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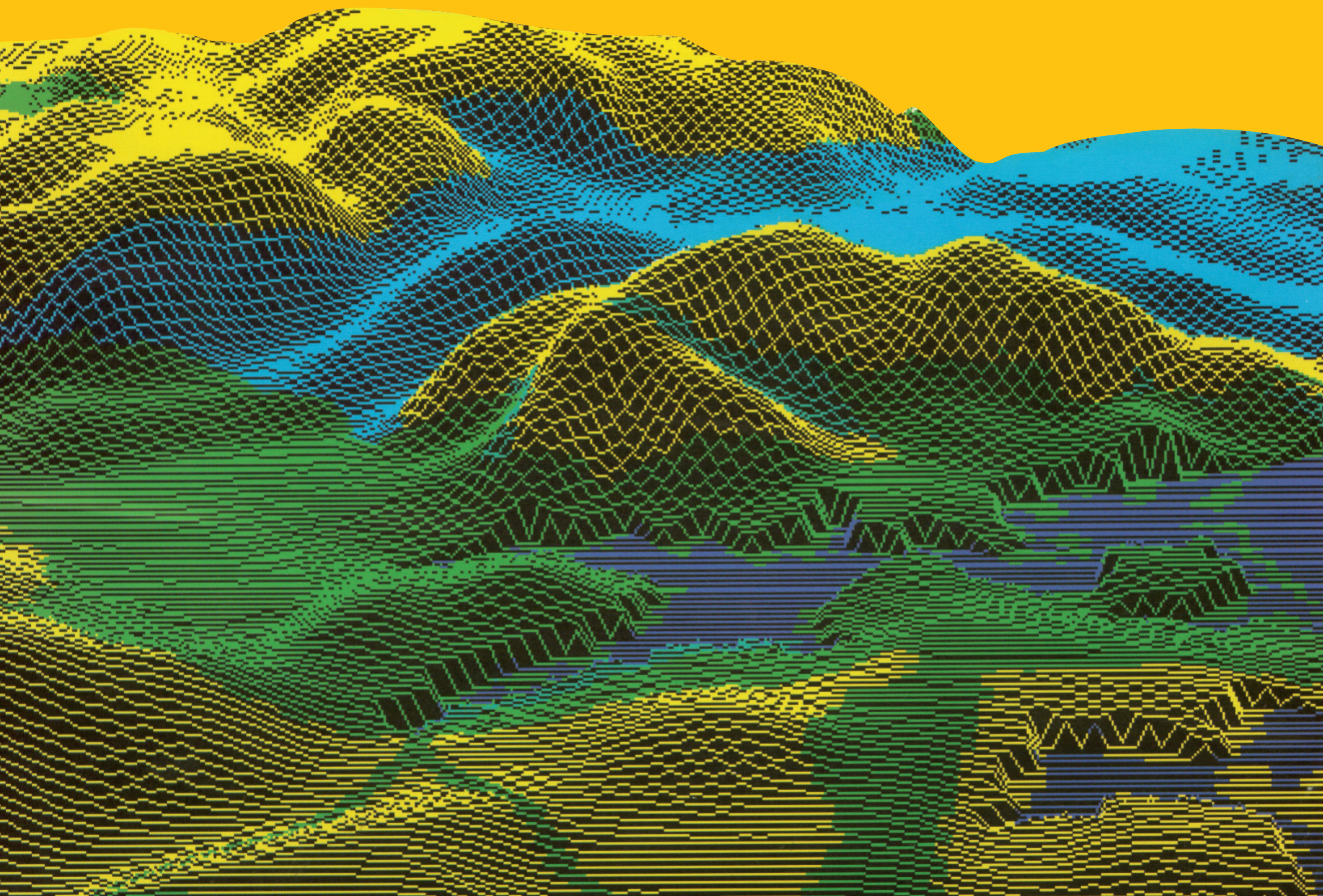

*Fig. 1: View to south-western direction from Špilberk castle (Mendel square, Brno Brewery, Fair Area, Bohunice Hospital and housing estates) (Photo P. Klusáček)*

*Fig. 2: Vaňkovka – example of the successful revitalisation of the industrial brownfield in Brno inner city (Photo P. Klusáček)*

Illustrations related to the paper by A. Maas

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## *Articles:*

# THE CORINE LAND COVER DATABASE OF SLOVAKIA AND ITS CHANGES IN THE PERIOD 2000 – 2006

Ján FERANEC, Jozef NOVÁČEK

**Abstract**

*The paper provides the basic characteristics of the CLC2006/GMES FTSP Land Monitoring Slovakia Project, aim of which was to update the CLC2000 database to the situation in 2006 and to identify the changes that took place in the concerned period in the context of all-European activities. Derivation of the CLC2006 and CLC2000/2006-change data has been accomplished by computer-aided visual interpretation of IRS and SPOT-5 satellite images. Basic statistical characteristics of identified CLC2006 classes, as well as the trends in land cover changes in Slovakia in the analysed six-year period where changes of forest into transitional woodland/scrub areas distinctly dominate are documented.*

**Shrnutí**

**Báze údajů o krajinné pokrývce Slovenska a jejích změnách v období 2000 –2006**

*Příspěvek poskytuje základní charakteristiky projektu CLC2006/GMES FTSP Land Monitoring Slovakia, jehož cílem bylo aktualizovat bázi údajů o krajinné pokrývce CLC2000 na stav roku 2006 a identifikovat změny v tomto období v kontextu celoevropských aktivit. Odvození údajů CLC2006 a CLC2000/2006-změny se uskutečnilo počítačem podporovanou vizuální interpretací satelitních snímků IRS a SPOT-5. Dokumentované jsou základní statistické charakteristiky identifikovaných tříd CLC2006 a trendy změn krajinné pokrývky Slovenska v analyzovaném šestiletém období, ve kterém výrazně dominují změny kategorie lesů na kategorii les/křovina.*

**Keywords:** *land cover, CLC2006, land cover change, satellite image, computer aided visual interpretation, Slovakia*

## 1. Introduction

The continuation of CORINE (Coordination of Information on the Environment) Programme in the field of land cover is an important contribution to knowledge of the European landscape. Geographers can use this data in the context of environmental and economic accounting (Uno and Bartelmus, 1998), assessment of landscape change and diversity, modelling of its properties, etc.

The project involved with the European Environment Agency (EEA) approved up-dating of the CLC2000 database to the situation in 2006 and identification of land cover changes in Europe in the period 2000 – 2006 under the title CORINE Land Cover 2006 – CLC2006 (EEA, 2007) in June 2005. This project became part of the all-European Global Monitoring for Environment and Security (GMES) Programme, particularly its servicing section of Fast Track Service Precursor Land Monitoring (FTSP Land Monitoring). The data obtained in this Programme will satisfy the requests of users on the all-European and national levels for preparation of various environmental strategies, evaluation of management in the network of the NATURA 2000 protected areas, evaluation of commitments adopted under agreements concerning climate change, evaluation of the common European agricultural policy and development of the rural area, in the development of the INSPIRE infrastructure (Infrastructure for Spatial Information in Europe) and the like (Feranec, 2008).

So far accomplished activities in Slovakia under the CLC90 and CLC2000 Projects have been described in studies of Feranec et al. (2000), Feranec and Oťaheľ (2001) and Feranec et al. (2005a, 2005b, 2007). The basic information on land cover of Slovakia and its changes in the period of 1990 – 2000 is also available on web pages of the Slovak Environmental Agency (SEA) (http://atlas.sazp.sk, http://dataservice.eea). These data obtained by a single methodology with discrimination of the minimum 25 ha area and the minimum 5 ha changes have laid foundations for a systematic analysis and assessment of land cover changes but also land use with indicators of biodiversity, etc. on an all-European level. The data obtained by intepretation of satellite images, apart from other, enrich or complement the national statistical data published in statistical yearbooks which characterize statistical classes and their use (kinds of plots) defined according to functional traits and updated every year by conventional methods in a detailed scale (Feranec and Oťaheľ, 2008).

The CLC1990 Project started in 1985 and involved the first 12 Member States of the European Community (Heymann et al., 1994). This and the following projects I&CLC2000 and CLC2006/GMES FTSP Land Monitoring encompass almost the whole of Europe, with the aim to provide consistent localized geographical information on land cover. The derived data concerning the land cover of Europe CLC90 and CLC2000 and the changes between 1990 and 2000 are also accessible on the website of the EEA (http://www.eea.europa.eu). The data allow research work in the area of landscape changes not only at the European but also at regional levels, as shown by recently accomplished projects in Europe – LACOAST, Phare Topic Link on Land Cover, MURBANDY, BIOPRESS, etc. (Feranec et al., 2007, 2009).

Slovakia joined the all European CLC2006/GMES FTSP Land Monitoring Project in 2007. The SEA seated in Banská Bystrica coordinated the Project at the national level while the Institute of Geography; Slovak Academy of Sciences (IG SAS) participated in interpretation of satellite images by means of which land cover of Slovakia and its changes in the period of 2000 – 2006 were identified.

The aim of this paper is to provide characteristics of the newly derived CLC2006 layer and above all layers concerning land cover changes in Slovakia in the period of 2000 – 2006 (CLC2000/2006), mainly for purposes of geographical landscape assessment.

## 2. Applied data and methods

The introductory step of the applied methodology was the revision of the CLC2000 data layer according to the Landsat 7 ETM satellite imagery from 2000 (+/– one year) carried out by computer aided visual interpretation in ArcView 3.2. For the national activities (scale 1:50 000), the existing thematic errors were removed in the CLC2000 data layer and areas with surface of 5 – 24 ha, for example those of *arable land* (211), *pastures* (231), or *forest enclaves* were identified above all in heterogeneous *agricultural areas* (243) (31 ×; codes of the CLC nomenclature are explained in Tab. 1). The corrected CLC2000 data layer represented the basic dataset for derivation of the new thematic CLC2006 layer.

The new CLC2006 data layer was derived by application of the IMAGE 2006 (IMA2006) geo-referenced base (IRS and SPOT satellite images from two time horizons: IMA2006-1: images from June to September; IMA2006-2: images from spring or autumn months (Fig. 1). The images from two time horizons made it possible to specify discrimination of pastures and arable land, annual and permanent crops, and the like.

The next steps of the methodology included:

- Segmentation of the corrected copy of the CLC2000 vector data according to the sequence of topographic maps at scale 1:100 000 that represented the initial CLC2006 data layer.
- Identification of CLC2006 classes by modification of the CLC2006 initial layer applying the satellite images IMA2006 by computer aided visual interpretation (Feranec et al., 2007). The criteria for identification of individual CLC classes and their changes, apart from interpretation elements (shape, size, colour, texture, pattern and association), also included the minimum surface of identified change in the LC area in the initial layer of CLC2006 against the expression on the IMA 2006 5 ha, the least identified width of the change was 100 m, and the least surface of the newly identified area had to be 5 ha (comparison of the criteria used in the context of CLC90, CLC2000 and CLC2006 Projects is in Tab. 2).
- Identification of LC changes in Slovakia in the period of 2000 – 2006 (CLC2000/2006) by overlay of CLC2000–CLC2006 data layers.
- Application of control procedures and tests (Feranec et al., 2005b; Büttner and Maucha, 2006).

## 3. Results

The first result of the CLC2006/GMES FTSP Land Monitoring Slovakia Project was the derived CLC2006 data layer. Its statistical characteristics are in Tab. 3. This data layer is accessible at www addresses of the SEA (http://atlas.sazp.sk, http://dataservice.eea). From the total number of 44 classes that constitute the CLC nomenclature (Tab. 1), 29 were identified in Slovakia. Compared to the CLC2000 data layer that of CLC2006 contains two classes less. In 2006, areas of gravel and gravel-sand banks (331 – *beaches*, *dunes*, *sand plains*) with surface equalling to or greater than 25 ha (presumably caused by the elevated the water stage of the Danube) and areas of burnt forest

| | |
|---|---|
| **1 Artificial surfaces** | **3 Forest and semi-natural areas** |
| 11 Urban fabric | 31 Forests |
| 111 Continuous urban fabric | 311 Broad-leaved forests |
| 112 Discontinuous urban fabric | 312 Coniferous forests |
| 12 Industrial, commercial and transport units | 313 Mixed forests |
| 121 Industrial or commercial units | 32 Scrub and/or herbaceous vegetation associations |
| 122 Road and rail networks and associated land | 321 Natural grasslands |
| 123 Port areas | 322 Moors and heathland |
| 124 Airports | 323 Sclerophyllous vegetation |
| 13 Mine, dump and constructions sites | 324 Transitional woodland-scrub |
| 131 Mineral extraction sites | 33 Open spaces with little or no vegetation |
| 132 Dump sites | 331 Beaches, dunes, sands |
| 133 Construction sites | 332 Bare rocks |
| 14 Artificial, non-agricultural vegetation areas | 333 Sparsely vegetated areas |
| 141 Green urban areas | 334 Burnt areas |
| 142 Sport and leisure facilities | 335 Glaciers and permanent snow |
| **2 Agricultural areas** | **4 Wetlands** |
| 21 Arable land | 41 Inland wetlands |
| 211 Non-irrigated arable land | 411 Inland marshes |
| 212 Permanently irrigated land | 412 Peat bogs |
| 213 Rice fields | 42 Maritime wetlands |
| 22 Permanent crops | 421 Salt marshes |
| 221 Vineyards | 422 Salines |
| 222 Fruit trees and berry plantations | 423 Intertidal flats |
| 223 Olive groves | **5 Water bodies** |
| 23 Pastures | 51 Inland waters |
| 231 Pastures | 511 Watercourses |
| 24 Heterogeneous agricultural areas | 512 Water bodies |
| 241 Annual crops with permanent crops | 52 Marine waters |
| 242 Complex cultivation patterns | 521 Coastal lagoons |
| 243 Land principally occupied by agriculture,with significant areas of natural vegetation | 522 Estuaries |
| 244 Agro-forestry areas | 523 Sea and ocean |

*Tab. 1: CLC nomenclature (Heymann et al., 1994; Bossard et al., 2000)*

(334 – *burnt areas*) are missing. Like in 2000, the greatest area was occupied by class 211 – *non-irrigated arable land* (1,701,235 ha), followed by classes 311 – *broad-leaved forest* (1,115,794 ha), 312 – *coniferous forest* (520,469 ha), 313 – *mixed forest* (418,818 ha), 242 – *complex cultivation patterns* and 243 – *land principally occupied by agriculture*, *with significant areas of natural vegetation* (400,501 ha).

Areas of class 243 are most abundant at scale 1:100 000; their frequency in Slovakia was 3,994. Classes 231 (3082), 324 (2754), 112 (2659), 313 (2456), 311 (2070), 211 (1750), 312 (1213) are also abundantly represented (see Tab. 3). The frequency of CLC classes also provides the picture about the landscape diversity of Slovakia.

The second result informs about land cover changes in Slovakia in the period of 2000–2006. Size of these changes is quoted in Tab. 4. Spatial distribution of identified changes and their thematic grouping in urbanized, agricultural and forest landscape is represented in Fig. 2.

Table 4 indicates that in 6-year period in Slovakia 76,924.6 ha of land cover changed. It equals 1.5% of the total country area (for comparison: during the decade of 1990–2000 the changes amounted to as much as 207,006 ha of land cover equalling to 4.2% of the total country area).

The most conspicuous identified change is enlargement of class 324 – *transitional woodland/*

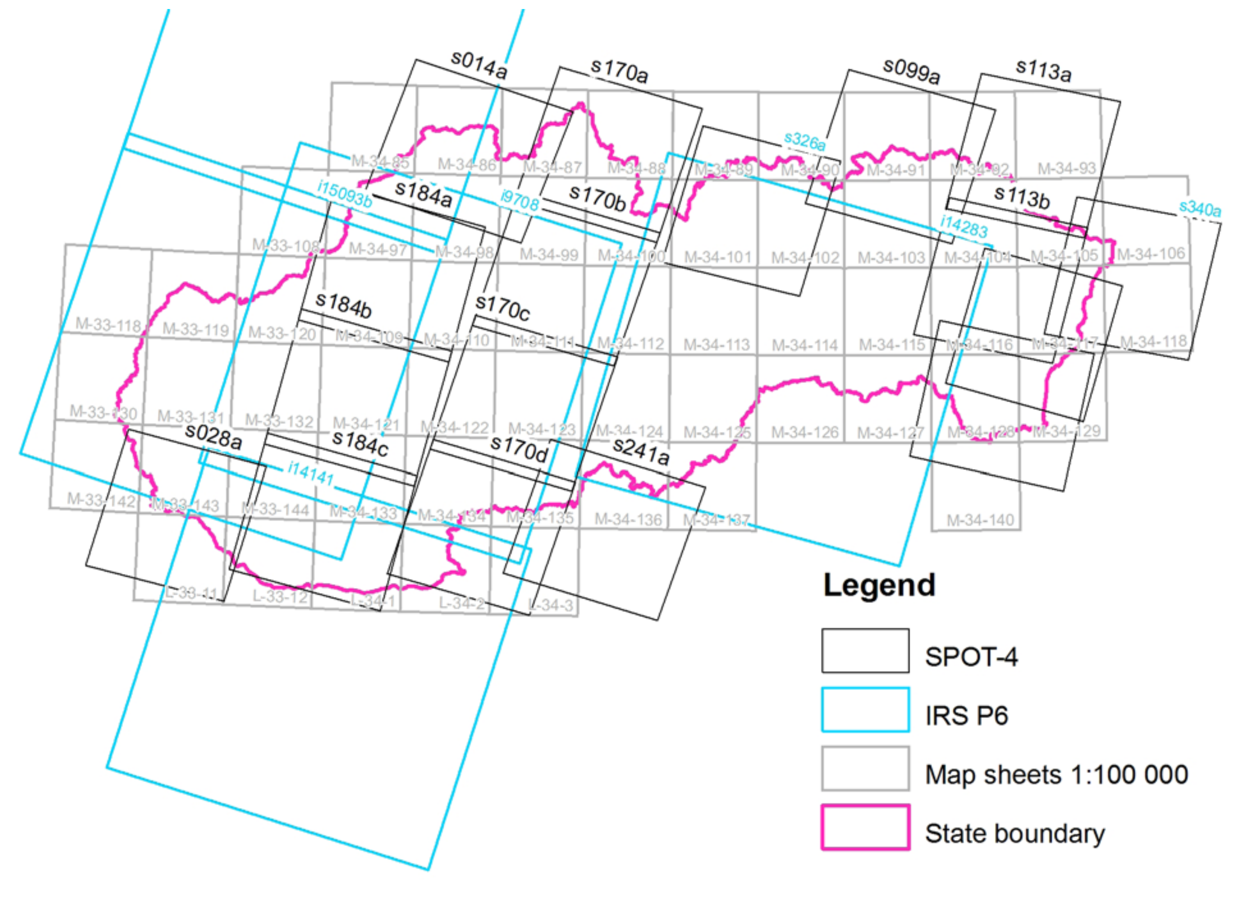


*Fig. 1: Overview of the map sheets on a scale 1:100 000 overlaid with IRS and SPOT data*

| | **CLC1990 Specifications** | **CLC2000 Specifications** | **CLC2006 Specifications** |
|---|---|---|---|
| Satellite data | Landsat-4/5 TM single date (in a few cases Landsat MSS, as well) | Landsat-7 ETM single date | SPOT-4 and/or IRS LISS III two dates |
| Time consistency | 1986–1998 | 2000 +/– 1 year | 2006+/– 1 year |
| Geometric accuracy satellite images | ≤ 50 m | ≤ 25 m | ≤ 25 m |
| CLC minimum mapping unit | 25 ha | 25 ha | 25 ha |
| Geometric accuracy of CLC data | 100 m | better than 100 m | better than 100 m |
| Thematic accuracy | ≥ 85% (not validated) | ≥ 85% (validated, see Büttner and Maucha 2006) | ≥ 85% |
| Change mapping | N.A. | boundary displacement min. 100 m; change area for existing polygons ≥ 5 ha; isolated changes ≥ 25 ha | boundary displacement min. 100 m; all changes > 5 ha have to be mapped |
| Production time | 10 years | 4 years | 1.5 years |
| Documentation | incomplete metadata | standard metadata | standard metadata |
| Access to the data | unclear dissemination policy | free access | free access |
| Number of European countries involved | 26 | 32 | 38 |

*Tab. 2: Evolution of CORINE land cover projects criteria (CLC2006 technical guidelines, 2007)*

*shrubs* (by 54,842 ha), above all at the cost of class 231 – *pastures* (3,714 ha), 311 (13,106 ha), 312 (32,556 ha) a 313 (4970 ha) (see Tab. 4). The severe windstorm that struck the areas of the Vysoké Tatry and Nízke Tatry mountain ranges on 19–20th November 2004 along with logging decisively affected the scope of change of class 312 into 324.

| CLC class | No of areas | Total area (in ha) | % from the country area |
|---|---|---|---|
| 111 | 11 | 765.64 | 0.02 |
| 112 | 2,659 | 222,501.49 | 4.40 |
| 121 | 361 | 29,051.15 | 0.57 |
| 122 | 47 | 2,955.28 | 0.06 |
| 123 | 3 | 187.75 | 0.00 |
| 124 | 21 | 2,433.75 | 0.05 |
| 131 | 73 | 3,228.27 | 0.06 |
| 132 | 30 | 1,593.22 | 0.03 |
| 133 | 21 | 1,279.36 | 0.03 |
| 141 | 23 | 1,244.65 | 0.02 |
| 142 | 145 | 8,697.40 | 0.17 |
| 211 | 1,750 | 1,701,234.84 | 33.66 |
| 221 | 283 | 23,883.00 | 0.47 |
| 222 | 181 | 11,115.97 | 0.22 |
| 231 | 3,082 | 284,107.12 | 5.62 |
| 242 | 869 | 69,176.50 | 1.37 |
| 243 | 3,994 | 331,324.96 | 6.56 |
| 311 | 2,070 | 1,115,793.56 | 22.08 |
| 312 | 1,213 | 520,469.20 | 10.30 |
| 313 | 2,456 | 410,817.70 | 8.13 |
| 321 | 135 | 30,262.87 | 0.60 |
| 322 | 84 | 14,978.88 | 0.30 |
| 324 | 2,754 | 215,255.60 | 4.26 |
| 332 | 7 | 6,784.96 | 0.13 |
| 333 | 60 | 5,373.01 | 0.11 |
| 411 | 61 | 3,003.89 | 0.06 |
| 412 | 3 | 238.88 | 0.00 |
| 511 | 107 | 14,843.56 | 0.29 |
| 512 | 134 | 21,430.55 | 0.42 |
| **Total** | **22,637** | **5,054,033.00** | **100.00** |

*Tab. 3: Statistical characteristics of the CLC2006 data layer of Slovakia (the 3rd level of CLC nomenclature; codes of classes are explained in Tab. 1)*

Enlargement of class 324 at the cost of class 231 is associated with the abandonment of originally agriculturally exploited pastures in the consequence of the new economic environment in the European Union (EU). A significant feature in the development of the forest landscape is the change of class 324 in favour of classes 311 (4,021 ha), 312 (1,193 ha) and 313 (4,134 ha) (see Tab. 3). Fig. 2 demonstrates that changes in forest have been most profound in districts of Kežmarok, Brezno and Čadca. They are minor in districts Žarnovica, Poltár, Revúca, Rožňava, Gelnica, Humenné, Námestovo, etc.

Changes in agricultural landscape have manifested by diminishment of class 211 in favour of classes 133 – *construction sites* (1,373 ha), 221 (843 ha), 231 (1,336 ha) and 242 (2,731 ha). The contrary process has also been observed: enlargement of the area of class 211 at the cost of above all classes 221 – *vineyards* (1,067 ha), 222 – *fruit trees and berry plantations* (495 ha), 231 (1,262 ha) and 243 (116 ha) (see Tab. 4). The observed dynamics in the agricultural landscape is attributable to the newly formed conditions of the agrarian policy both on the national and European level. Enlarged area of class 242 at the cost of class 211 in districts Galanta, Šaľa, Dunajská Streda, Nové Zámky and Komárno (see Fig. 2) is presumably connected with the lease of land to new lessees who mostly change over from large-scale farming to small-area farming. Enlargement of class 221 (see Fig. 2) is evident in district Trebišov.

The most distinct among identified changes in the context of urbanized landscape is enlargement of class 133 (by 1,853 ha) above all at the cost of class 211 (see Tab. 4) associated with construction of commercial and industrial areas (such as car-making factories of PSA Pegueot Citroën or KIA) and of motorways. Frequency of such activities is proper to districts of Trnava, Bytča, Žilina and Poprad (see Fig. 2). The developmental trend in urbanized landscape also manifested in enlargement of classes 112 – *discontinuous urban fabric,* 121 – *industrial or commercial units*, 122 – *road and rail networks and associated land* and 131 – *mineral extraction sites*, above all at the cost of agricultural landscape (for instance in districts Bratislava, Pezinok, Senec, Kežmarok and Košice).

## 4. Conclusion

The presented characteristics of land cover in Slovakia are the results of successful cooperation of the IG SAS with the SEA in the CLC2006/GMES FTSP Land Monitoring Slovakia Project.

| Area in ha | CLC00 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CLC06** | **131** | **132** | **133** | **142** | **211** | **221** | **222** | **231** | **242** | **243** | **311** | **312** | **313** | **321** | **324** | **331** | **333** | **Total area** |
| **112** | | | 195.42 | 7.38 | 92.38 | | | | | 16.66 | | 15.14 | | | | | | 326.97 |
| **121** | | | 7.92 | | 916.76 | | | | 15.91 | 20.34 | | 20.97 | | | 14.75 | | | 996.64 |
| **122** | | | 214.43 | | | | | | | | | | | | | | | 214.43 |
| **131** | | | | | 280.10 | | | | 6.37 | 16.82 | 16.48 | 12.23 | 10.43 | | | | | 342.44 |
| **132** | | | 26.45 | | | | | | | | | | | | 7.90 | | | 34.35 |
| **133** | | | | | 1,372.74 | 65.20 | | 157.87 | 15.38 | 146.51 | 22.05 | 9.57 | 58.26 | | 5.86 | | | 1,853.43 |
| **142** | | | | | 74.76 | | | | 33.36 | | | | 5.75 | | | | | 113.88 |
| **211** | | | 94.70 | | | 1,066.50 | 494.78 | 1,262.00 | 95.83 | 116.44 | | | | | | | | 3,130.25 |
| **221** | | | | | 843.09 | | | | | | | | | | | | | 843.09 |
| **222** | | | | | 129.99 | | | | | | | | | | | | | 129.99 |
| **231** | | 27.11 | | | 1,336.28 | 100.03 | 15.99 | | | 348.02 | | | | | | | | 1,827.43 |
| **242** | | | | | 2,731.18 | | | | | | | | | | | | | 2,731.18 |
| **243** | | | 31.84 | | | | | | | | | | | | | | | 31.84 |
| **311** | | | | | | | | | | | | | | | 4,020.94 | | | 4,020.94 |
| **312** | | | | | | | | | | | | | | | 1,193.23 | | | 1,193.23 |
| **313** | | | | | | | | | | | | | | | 4,133.58 | | | 4,133.58 |
| **324** | 37.81 | | | | | | 10.50 | 3,713.78 | | | 13,105.67 | 32,555.63 | 4,969.77 | 50.58 | | 65.54 | 333.18 | 54,842.45 |
| **512** | | | | | 109.54 | | | 7.04 | | 20.40 | 6.41 | | | | 15.06 | | | 158.45 |
| **Total area** | 37.81 | 27.11 | 570.75 | 7.38 | 7,886.82 | 1231.72 | 521.28 | 5,140.69 | 166.84 | 685.19 | 13,150.61 | 32,613.53 | 5,044.21 | 50.58 | 9,391.33 | 65.54 | 333.18 | 76,924.56 |

*Tab. 4: Land cover changes of Slovakia in 2000–2006*

The newly derived CLC2006 data layer along with CLC2000 and CLC90 data layers are important information sources which facilitate analysis, assessment and map representation of varied environmental aspects of the landscape both on the national and all-European levels.

Other obtained results reveal that in Slovakia in the period of 2000–2006, 76,925 ha of land cover changed. The figure includes above all the change of 54,842 ha of forest into *transitional wood/scrub*, followed by the change of 9,348 ha of *transitional wood/scrub* into forest, but also changes of 2,731 ha of *arable land* into complex cultivation pattern or change of 1,373 ha of *arable land* into complex cultivation pattern and 1,336 ha of *arable land* into *pastures* and other changes.

The remarkable about the data about land cover of Slovakia and its changes identified under the CLC projects is that besides spatial correctness they are compatible and comparable at a ;supranational level and landscape changes can be represented on maps at an almost all-European level.

The paper is one of the outputs of the Structure of the rural landscape: analysis of the development, changes and spatial organization by application of the CORINE land cover databases and the geographical information systems Project No. 2/7021/7 pursued at the Institute of Geography of the Slovak Academy of Sciences in 2009, supported by the VEGA Grant Agency. Authors are grateful to Hana Contrerasová for translation of this paper into English.

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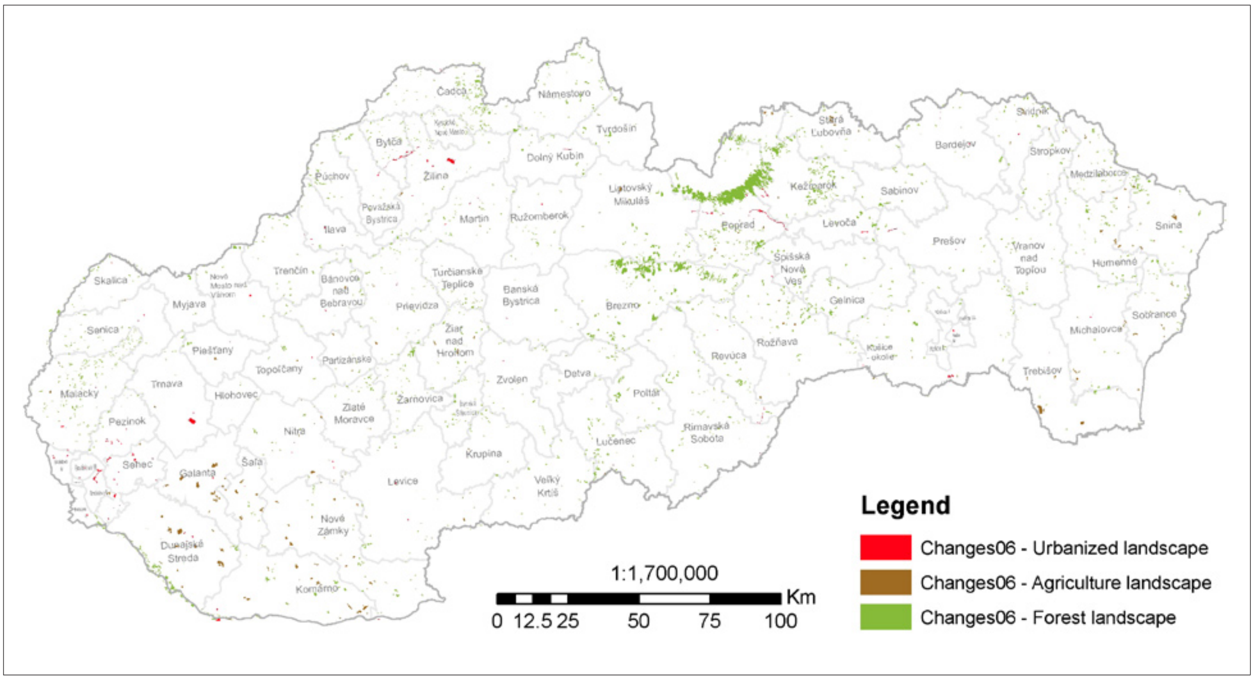


*Fig. 2: Spatial distribution of CLC2000/2006 changes in Slovakia and their thematic aggregation into urbanized landscape, agricultural landscape and forest landscape (changes classified into urbanized landscape: 133-112, 133-121, 133-122, 211-112, 211-121, 211-131, 211-133, 231-133, 243-112, 243-121, 243-133; changes classified into agriculture landscape: 211-221, 211-222, 211-231, 211-242, 221-211, 222-211, 231-211, 243-231, 243-211, 242-211; changes classified into forest landscape: 231-324, 311-324, 312-324, 313-324, 324-311, 324-312, 324-313, 333-324; other minor changes are not included in the map).*

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# THE INFLUENCE OF SITE CONDITIONS ON THE IMPACT OF WINDSTORMS ON FORESTS: THE CASE OF THE HIGH TATRAS FOOTHILLS (SLOVAKIA) IN 2004

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**Abstract**

*The windstorm on 19$^{th}$ November 2004 caused a great deal of damage to forests of the Tatras National Park. It has changed the environment of the impacted areas in the High Tatras foothills for a long time. The impact of the wind calamity on various types of sites is presented in this article, on the basis of large-scale geo-ecological field research. For the first time, a generalized additive model is applied to model this event. Its results signal possible influence of site conditions on local disturbances of spruce woods and mixed pioneer woods. The results are important for the needs of integrated assessments of the research area and for forest management.*

**Shrnutí**

***Význam stanovištních podmínek na důsledky vichřic v lesích: případ úpatí Vysokých Tater (Slovensko) v roce 2004***

*Vichřice 19. listopadu 2004 způsobila velké škody v lesích patřících do Tatranského národního parku. Změnila životní prostředí v zasažené oblasti na dlouhý čas. V tomto příspěvku je prezentován výsledek vlivu větrné kalamity na různých typech stanovišť, založený na rozsáhlém geoekologickém terénním výzkumu. Poprvé byl pro takovýto druh výzkumu použit zjednodušený aditivní model. Výsledky signalizují vliv stanovištních podmínek na lokální poškození smrkových lesů a pionýrských smíšených porostů. Získané informace jsou cenné pro potřeby integrovaného hodnocení životního prostředí zkoumaného území a pro lesní hospodářství.*

***Keywords:*** *geo-ecological research, generalized additive models, forests, site conditions, wind calamity, Tatras National Park, Slovak Republic.*

## 1. Introduction

The calamity situation for the forests of the Tatras National Park (TANAP), caused by the windstorm on 19$^{th}$ November 2004, was exceptional in terms of its unusual size. The area of TANAP was affected by winds of velocities reaching up to 200 km.hr$^{-1}$. More than 120 square kilometres of the foothill forests were damaged. The wind calamity caused wind slashes and wind throws and affected the environment of the impacted areas in the long term.

Quantitative methods have become more than just complementary features to qualitative methods in the recent physical-geographical and landscape-ecological research. The understanding of the impact of wind forces on trees, by using geographical information systems (GIS) for evaluation of the level of damage, is one of the main topics of recent landscape-ecological, bio-geographical and forest research (Wright, Quine, 1993; Wood, 1995). Statistical evaluation of the influence of site conditions on windstorm impact on forests, however, is still a sporadic topic in current research. Geographical fieldwork databases provide opportunities for using statistical methods. The paper presents possibilities of studying the impact of wind calamities on various types of sites, on the basis of large-scale geo-ecological field research and statistical methods.

The aim of this paper is to describe the influence of site conditions on the windstorm impact in chosen representative localities in the High Tatras foothills (Fig. 1), using generalized additive models (GAM). We evaluate dependences between site conditions (abiotic components of the geotope) and the actual state of the tree layers of the forests after the wind calamity in this case. In the area under study, similar strong windstorm events are repeated about once every hundred years. In this context, the modeling of the impact of the wind calamity on various types of sites on the basis of large-scale geo-ecological field research, is presented for the first time using generalized additive models. These models are used to estimate the number of standing trees in the area impacted by windstorms in a more flexible manner than traditional linear regression models.

## 2. Geo-systems and their changes by windstorms

A geo-system (S) can be formulated by the following scheme (Krcho, 1991):

$$S = (G\ (P,T),\ R(P,T)),$$

where $G$ is a set of system elements, $R$ is a set of inter-relations between elements, $P$ is a function of geographical location, and $T$ is a function of time.

In geo-systems, evolutionary changes are in process [functions of location and time], but their dynamic balance can be disturbed. Significant disturbances in forest geo-systems are caused by wind calamities. The most vulnerable components are represented by flora and fauna. Vegetation cover presents an important part of the secondary landscape structure. Biotope mapping in the terrain is time-consuming; therefore, to evaluate the spatial structure changes, land cover maps are used. The evaluation of changes in land cover contributes markedly to the assessment of forest disturbances caused by wind storms.

Forman (2003) discusses methodological issues with respect to landscape structure evaluation and landscape changes. Bičík and Hymiyama (2005) deal with land use and land cover changes in a global and regional context, while Lipský (2000) and Olah et al. (2006) focus on chosen territories in the Czech and Slovak Republics. Kolejka and Trnka (2008) express concerns about the theoretical starting points for study and the research reality in the field of landscape change assessment. Nowadays, CORINE Land Cover methodology is often used by landscape ecologists and geographers in the European Union: Oťaheľ et al. (2003) applied such a methodology for landscape change assessment; Falťan and Saksa (2007) and Falťan and Bánovský (2008) described land cover change of the High Tatras foothills caused by wind calamities.

In forestry praxis, the term 'calamity' means extensive damage to forests that disrupts their integrity significantly in the form of huge wind throws, wind slashes or standingt dead trees. Strong wind events impact forests over the globe in both temperate and tropical regions. The catastrophic windstorm is a recurrent phenomenon in the Tatras region. Similar (but mainly less catastrophic) events occurred in the years 1898, 1915, 1919, 1968, 1980 and the year 2002 (Koreň, 2005). The very rugged topography of the Tatras forms various conditions for airflows and local winds. Jeník (2000) defined this complex of natural phenomena in mountain areas with local winds as an anemo-orographic system. The windstorm event had the character of a bora that tumbled over the

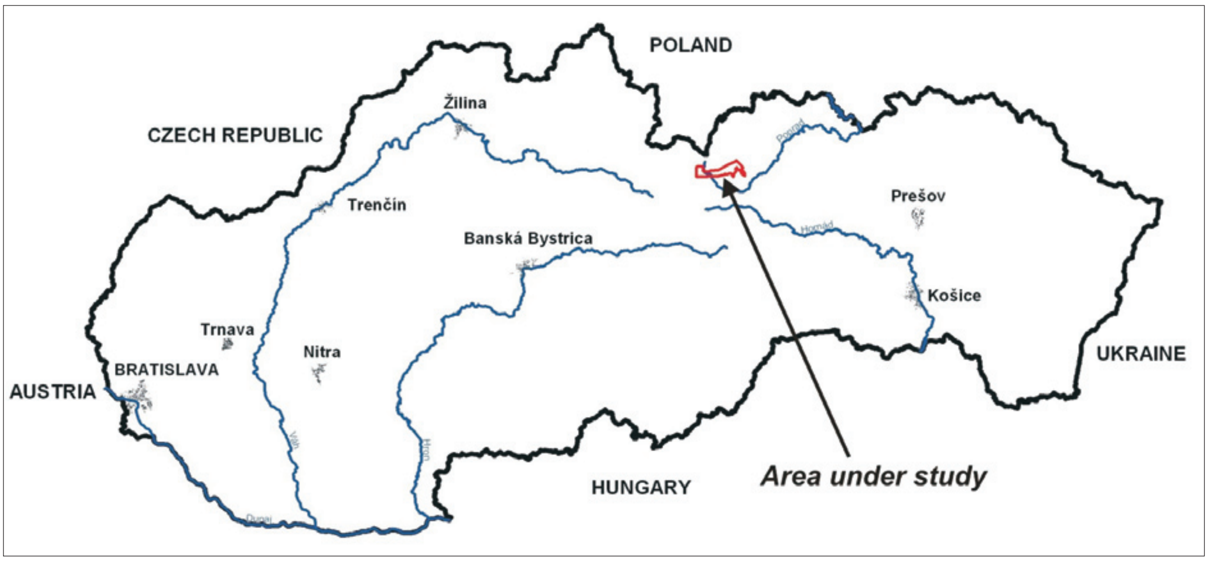


*Fig. 1. Area under study*

Tatra ridges from the north and north-west and stuck the foothills, where maximum damage was recorded (Balon and Maciejowsky, 2005).

The current results of research on the areas damaged by winds were published (e.g., Fleischer and Matejka, 2007; Majlingová and Ponce, 2007), but these authors were mainly concerned with analytical investigations after the calamity in TANAP and a comprehensive geo-ecological approach is lacking. We assume that the response of the elementary local geo-systems (geotopes) to disturbance has a synergetic character, and therefore geographical regionalization and statistical analysis should be an adequate tool for the investigation of detailed territorial differences in forest damage. Examples from other regions (e.g., Kramer et al., 2001; Mikita et al., 2009) have a similar, comprehensive geo-ecological approach.

We represent the calamity situation after the windstorm in the High Tatras as a reaction of local (topical) geo-systems (geotopes, which consist of abiotic site and biotic cover) to a disturbance input. Every disturbance input affects mainly the system of elements and the system of interactions, which determines the local effects of the disturbance. Disturbance is manifested as wind throws and slashes (Fig. 2). The preliminary published results (Minár et al., 2008) were complemented by an expanded dataset and the use of a new method.

## 3. Material and methods

An approach using methods of detailed field geo-ecological research and mapping (Minár et al., 2001), was used for data collection in the surroundings of four post-calamity research areas of the State Forests of TANAP (Fig. 3): Vyšné Hágy (reference, intact forest), Tatranská Lomnica – Jamy (non-extracted forest), Danielov dom (extracted forest), Tatranské Zruby (extracted, burnt forest). We recorded 260 research points (tesserae) in the years 2006–2008. They were localised for recording of local differences between more and less damaged topical geo-systems. Existing vegetation units were recorded by the CORINE Biotopes (Ružičková et al., 1996) and NATURA 2000 (Stanová and Valachovič, 2002) project methodologies.

We described local characteristics of geo-relief, bedrock, soils, type and percentage of land cover units and level of damage to the existing vegetation during fieldwork. The geographical position of research points (tesserae) was established by a global positioning system (GPS) receiver and interpreted in the environment of GIS ArcInfo 9. Figure 4 demonstrates land cover changes in the study area.

The evaluation stage of the research was as follows. Classification of the tesserae into types of geotopes (topical physio-geographical units) and evaluation of their disturbance, was the approach used at first. We used geo-relief (landforms) as a leading factor in the classification. Simple statistical analysis was useful in the complex vegetation damage assessments of the various geotopes.

Complex statistical analysis of site conditions and damage to the tree layers was performed in the R computing environment (R Development Core Team, 2008), freely

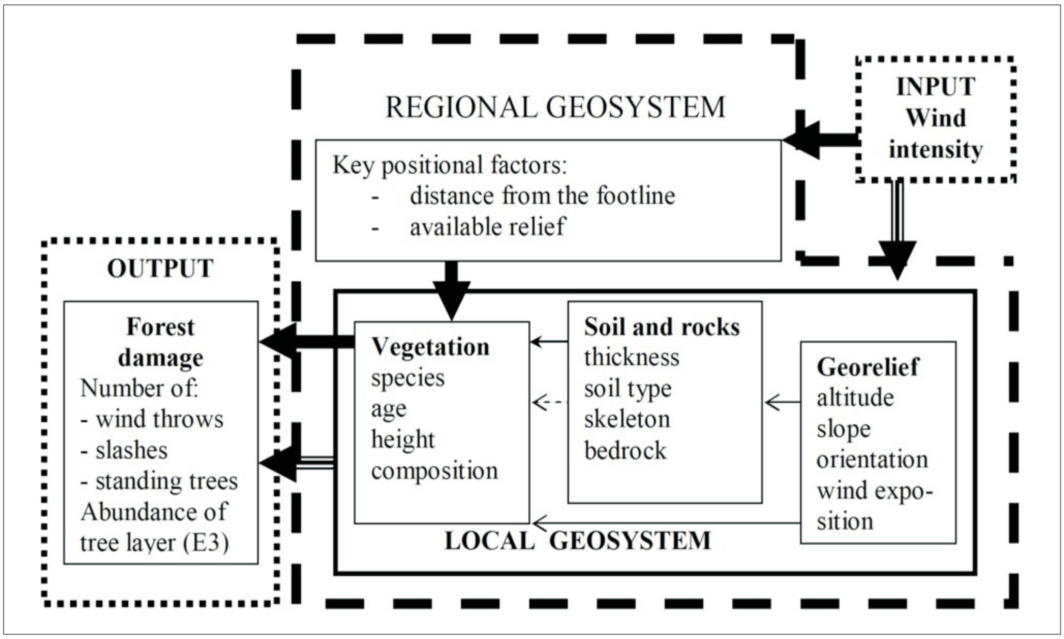


*Fig. 2. System scheme of wind disaster and relevant properties of its elements (Minár et al., 2008, adapted)*

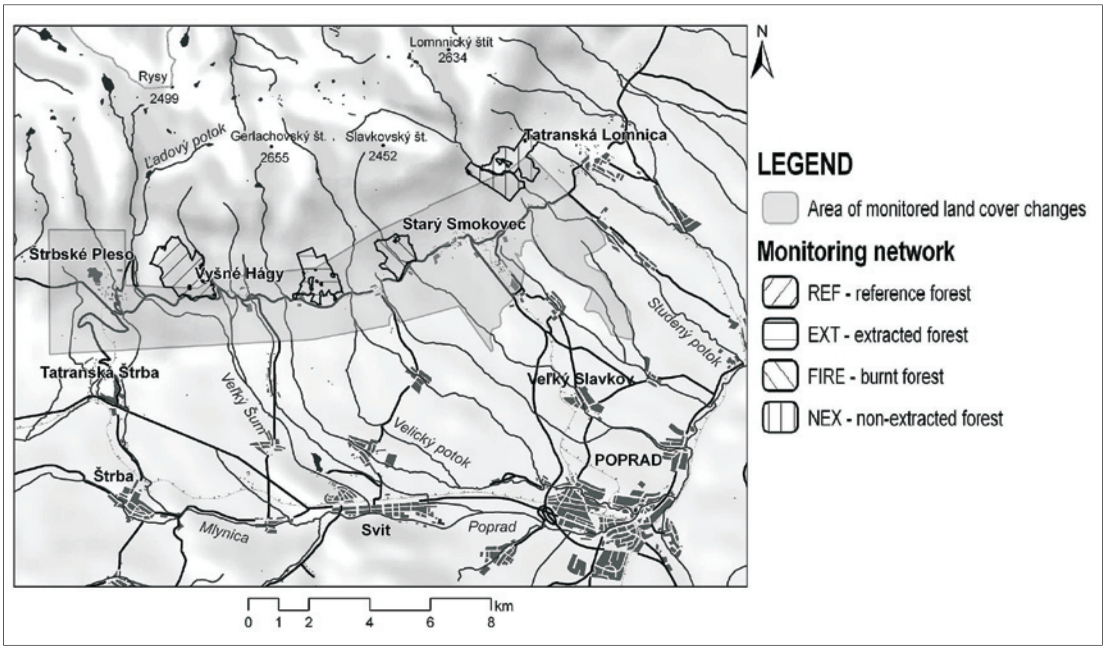


*Fig. 3: Permanent research fields assigned by the management of the Tatras National Park*

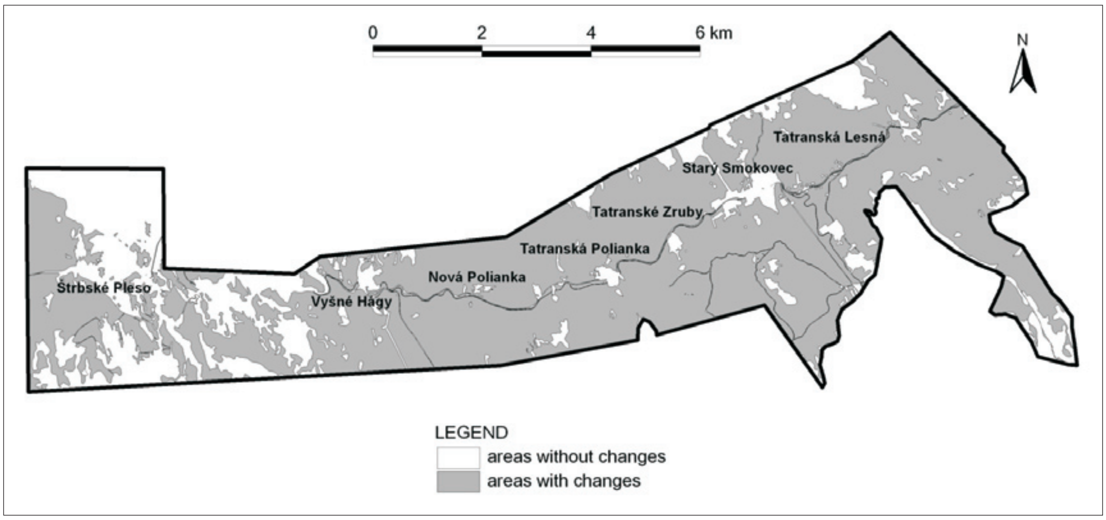


*Fig. 4: Areas with land cover changes*

downloadable from http://cran.r-project.org/). We submitted data to GAM based on penalized regression splines (Wood, 2006) as a part of the mgcv R package to determine any casual relationships between the dependent variable, number of standing trees, and a set of independent variables (Tab. 1).

In an ordinary linear regression model, parameters are estimated by minimization of ordinary least squares (OLS). This model is not appropriate in this case study because of possible nonlinear relationships between the dependent variable and the set of independent variables (as mentioned above).

The methodology behind the GAM has a greater flexibility than the traditional OLS model. It relaxes the usual linear parametric assumptions, and enables researchers to uncover structure in the relationships between the independent variables and the dependent variable that might otherwise be missed. In this type of modeling, OLS is replaced by penalized least squares (Hastie et al., 2003). Each of the individual additive terms is estimated using a univariate smoother termed as a penalized regression spline. An optimal model is chosen via generalized cross-validation in order to maximize the ability of the model to predict the data to which it was not fitted (Wood, 2006). This algorithm is applied to each variable (as an additive term) separately and all estimated parameters together form the GAM.

We extracted an optimal model by stepwise model selection using the Akaike Information Criterion (AIC, Venables and Ripley, 2002), to enter only the variables having an important relationship to the fitted dependent variable in the model. The results are presented with directions of dependence (↑ positive and ↓ negative dependence) and statistically significant p-values (significance level α is equal to 0.05; if p-value is less than α, null hypothesis about independence of the number of standing trees on independent variables is rejected and alternative hypothesis about casual dependence is inferred as valid).

## 4. Results

The study area is situated between the settlements of Štrbské Pleso and Tatranská Lesná. It represents all types of landscape systems in the area affected by the calamity. It lies at the boundary of the geomorphologic units Tatras and Podtatranská basin (Mazúr and Lukniš, 1980). Plesník (2002), in his phytogeographical-vegetational division, places the study area into the coniferous zone. Before the wind calamity, the actual vegetation of the area consisted mostly of planted spruce growths, spruce-bilberry forests, mixed pioneer forests and fir-spruce forests. After the calamity, one can find mainly clearings with processed woods. In lower areas, a mosaic of mixed forests has been identified.

We analyzed the relationships between site conditions and the level of vegetation cover damage (coverage, standing trees, slashes and wind throws in an area of 100 $m^2$). The main categories of the groups of geotopes (Tab. 2) are: fault slope, erosional slope, erosional-denudational slope, denudational slope, colluvial slope, ridge, gentle inclined flat, saddle, moraine, rockfall accumulation, glacifluvial cone, floodplain. We also investigated the type of bedrock

| Conditions | Variable abbreviation | Units | Explanation of the variables |
|---|---|---|---|
| Position | α | no. | latitude |
| | λ | no. | longitude |
| | altitude | no. | metres above sea level |
| Geo-relief | slope angle* | degree | angle of the slope |
| | orientation* | degree | orientation of the slope |
| | quadrant | no. | quadrant of orientation of the slope |
| Soil | H1.depth* | cm | depth of the first soil horizon |
| | H2.depth | cm | depth of the second soil horizon |
| | H1.skeleton* | % | volume of skeleton in the first soil horizon |
| | H2.skeleton | % | volume of skeleton in the second soil horizon |
| | H1.average skeleton size* | cm | average skeleton size in the first soil horizon |
| | H2.average skeleton size | cm | average skeleton size in the second soil horizon |
| | H1.maximum skeleton size* | cm | maximum diameter of the skeleton in the first soil horizon |
| | H2.maximum skeleton size | cm | maximum diameter of the skeleton in the second soil horizon |
| | soil type | - | soil type according to soil classification |
| Vegetation | maximum tree height* | m | maximum height of the standing trees |

*Tab. 1: Input variables into the model (* - variables in the optimal model)*

and soil type for every geotope for a description of the site conditions. Generally, granites create the bedrock in this area.

We evaluated damage to the tree layer in relation to relevant site conditions. 933 slashes and 857 wind throws were recorded in all 260 records on tesserae. The average number of standing trees, slashes, wind throws and abundance of tree layer (E3) for every type of geotope are presented in Tab. 2.

Sites exposed to the impact of the windstorm (e.g. saddles, colluvial slopes and moraine elevations) with planted spruce growths and spruce-bilberry forests (Fig. 4) were significantly damaged. Soil cover did not have so strong an impact on the level of damage, but generally, sites with hardened bedrock were less damaged than those with crushed bedrock. We can see a hydro-morphed effect of soils in this territory. Firstly, the natural vegetation on Gleysols and Fluvisols is relatively less harmed. Secondly, there is

| Landform | Bedrock | Soil type | Records | Standing trees | Slashes | Wind throws | Tree layer (%) |
|---|---|---|---|---|---|---|---|
| fault slope | granite | Cambic Podzols | 5 | 16.75 | 0.20 | 0.60 | 54.00 |
| erosional slope | granite | Cambic Podzols | 11 | 14.60 | 2.27 | 2.45 | 32.00 |
| erosional slope | granite | Sceletic Leptosols | 23 | 12.30 | 3.22 | 2.13 | 30.96 |
| erosional-denudational slope | granite | Cambisols | 17 | 10.53 | 4.35 | 3.35 | 30.07 |
| undistingued moraine | block granite moraine | Cambic Podzols | 26 | 9.04 | 1.92 | 2.88 | 28.27 |
| denudational slope | granite | Cambic Podzols | 11 | 8.90 | 3.91 | 2.54 | 28.09 |
| gentle inclined flat | granite | Cambisols | 10 | 9.56 | 5.00 | 4.70 | 26.00 |
| steep morenic slope | block granite moraine | Cambic Podzols | 35 | 7.29 | 3.29 | 4.04 | 25.29 |
| rockfall accumulation | granite | Lithic Leptosols | 4 | 12.75 | 3.25 | 1.50 | 24.75 |
| glacifluvial cone | glacifluvial matherial | Cambic Podzols | 8 | 5.13 | 5.38 | 4.38 | 23.06 |
| floodplain | fluvial holocene matherial | Fluvisols | 7 | 13.67 | 3.00 | 3.71 | 22.83 |
| depression in moraine | till | Haplic Gleysols | 14 | 11.07 | 3.36 | 3.29 | 22.21 |
| distinctive skeletal moraine | block granite morraine | Lithic Leptosols | 7 | 10.14 | 3.14 | 4.57 | 18.86 |
| ridge | granite | Cambisols | 7 | 12.00 | 6.71 | 1.86 | 18.59 |
| erosion-denudational slope | granite | Cambic Podzols | 11 | 9.00 | 3.45 | 3.00 | 18.00 |
| depression in moraine | till | Cambic Podzols | 16 | 8.33 | 2.88 | 4.06 | 16.33 |
| gentle morenic slope | block granite moraine | Cambic Podzols | 10 | 4.80 | 4.90 | 3.20 | 14.70 |
| colluvial slope | granite colluvium | Cambic Podzols | 21 | 4.76 | 4.76 | 3.66 | 14.00 |
| elevation in moraine | block granite moraine | Cambisols | 13 | 5.46 | 3.85 | 5.54 | 9.77 |
| saddle | granite | Haplic Podzols | 4 | 0.33 | 6.25 | 6.25 | 8.50 |

*Tab. 2: Damage to vegetation cover on basic types of geotopes recorded during fieldwork*

a tendency that the level of damage increases with increases of soil moisture in other soil types, such as Leptosols, Cambisols and Podzols. The vegetation on ridges was damaged mostly by slashes (Slashes/Wind throws = 3.61), fault slopes were damaged mainly by wind throws (Slashes/Wind throws = 0.33). Spruces (Picea abies) in particular have been affected by both of them. Larches (Larix decidua) seem to be more resistant. Pines (Pinus sylvestris) have been affected less by wind throws. Trees in the pioneer forests, especially birch (Betula pendula), aspen (Populus tremula), and alder (Alnus incana), were generally less damaged (Fig. 5 – see cover p. 4). The average abundance of the tree layer in all records was 22.72%.

Overall values show the large kinetic energy of wind. Spruces in the monocultures have higher damage values because of greater density than the natural spruce forests. Generally, spruces are more affected by wind throws for their shallow root system.

Relationships between the number of standing trees in research localities after the wind calamity and relevant elements of the geo-system are discussed subsequently. The optimal model for the number of standing trees has a following form (explained deviation is equal to 60.8 %):

Number of standing trees = H1.depth + H1.skeleton + $f$ (H1.average skeleton size) + H1.maximum skeleton size + $f$ (slope angle) + orientation + $f$ (maximum tree height),

where f is a smooth function (penalized regression spline). The number of standing trees depends linearly on H1.depth (↓), H1.skeleton (↓), H1.maximum skeleton size (↑) and orientation (↑, p-value = 0.0114), and nonlinearly on slope angle (↑,p-value = 0.0037), maximum tree height (↑,p-value < 0.0001) and H1.average skeleton size (↑,p-value = 0.0027). As we can see from the above, insignificant variables stay in the model because their impact on the model quality (explained deviation) is not ignorable in the sense of AIC.

The number of standing trees in the belt under the High Tatras footline (almost totally affected by the windstorm) is not dependent on latitude and longitude. Geographical position has an influence on the windstorm impact only above the footline, in combination with steep slope angle. The characteristics of the second soil horizon do not affect damage to the tree layer. The most important site conditions observed were the characteristics of the first soil horizon (depth, skeleton), slope angle and orientation. The maximum height of the standing trees was recorded in old spruce-bilberry forests above the footline. The more damaged spruces in monocultures were lower, with a higher tree density.

There were small abundances of trees recorded on the slopes with north-western aspect (dominant wind course). Generally, trees were less damaged in localities with higher values of slope angle, skeleton size, non-oriented to the windstorm course, with lower skeleton volume and shallow humus horizon. Representative examples of these characteristics are sites of fault and erosional slopes above the footline, covered by old natural spruce-bilberry and fir forests. Lower numbers of standing trees were observed in the wind-exposed sites with lower slope angle, higher volume of skeleton and wider humus horizon. Examples of the most damaged geotopes are saddles and colluvial slopes in moraines covered by spruce monocultures.

## 5. Conclusions

The Tatras National Park has been founded on the 1st of January 1949 as the oldest national park in Slovakia with an aim to preserve a diversity of the landscape systems of Tatras and the surrounding basins with a variability of a nature. The catastrophic windstorm is a repetitive phenomenon in the Tatras region. More than 120 square kilometres of foothill forests were damaged on the 19th of November 2004. Average cross size of the wind calamity area is 3.5 km, approximately 3 km wide belt with damaged forests lies under the footline.

We described the influence of the site conditions on the windstorm impact on forests in the High Tatras foothills in 2004 by GAM. Firstly, we recorded damage of the tree layer of various geotopes. Secondly, results of statistical analysis of the relations between damage level and individual site conditions were presented. Geotopes of saddles, elevations of moraines and colluvial slopes with planted spruce growths have been damaged the most. Small damage was recorded on sites of fault, erosional and denudational slopes with spruce-bilberry and fir forests, depressions and slopes of moraines covered with mixed pioneer forests. Especially spruces have been affected by wind; larches seem to be more resistant. Pines have been affected less by wind throws.

Statistical analysis of site conditions was performed in R software. We submitted data to the GAM based on penalized regression splines to find out casual relationship between dependent variable and set of relevant independent variables. Ordinary linear regression model is not appropriate in this situation because of nonlinear relationship of dependent variable with independent variables. Based on the GAM used, we found middle dependence between characteristics of forest damage caused by the windstorm (number of standing trees) and relevant site conditions (depth and skeleton of the first soil horizon, slope angle, orientation). Trees were less damaged in localities with higher values of slope angle, skeleton size, with lower skeleton volume and shallow humus horizon. Results can be used for integrated environmental assessment of the calamity area and in the process of out-planting proposals in the areas of TANAP with lower level of conservation.

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# ANALYSIS OF RELIEF IMPACT ON TRANSPORT DURING CRISIS SITUATIONS

Marian RYBANSKÝ, Miroslav VALA

**Abstract**

*The goal of this paper is to identify the critical relief factors in terrain, which are important for the transportation analyses and cartographic visualization, especially for crisis situations and natural disasters such as floods, fires, storms, military operations etc. Both relief parameters and technical parameters of vehicles are important for cross-country movement analyses focused on the tracking and visualization of the shortest, fastest, or safest routes in the terrain. The paper presents results of cross--country movement analyses using mathematical and statistic methods. To verify the methods, results were used from laboratory and field tests and measurements. The tests and visualizations of research results were made with using the main military (wheeled and tracked) vehicles and the ARC GIS Software. The paper presents partial results from the defence research project "METEOR" 0801 8 6020R and from the research programme VZ FVT 0000401 managed by the University of Defence Brno.*

**Shrnutí**

**Analýza vlivu reliéfu na dopravu v krizových situacích**

*Cílem článku je identifikovat kritické faktory terénu, které jsou důležité pro analýzy dopravy a kartografickou vizualizaci, zejména pro krizové situace a přírodní pohromy jako záplavy, požáry, vichřice, vojenské operace apod. Jak parametry reliéfu, tak i technické parametry vozidel jsou důležité pro provádění analýz průchodivosti terénu se zaměřením na hledání a vizualizaci nejkratších, nejrychlejších nebo nejbezpečnějších tras v terénu.V příspěvku jsou zahrnuty výsledky analýz průchodivosti terénu s využitím matematických a statistických metod. Pro verifikaci těchto metod byly ve výzkumu rovněž využity výsledky laboratorních a terénních testů a měření. Pro testy a vizualizaci výsledků výzkumu byly využity hlavní vojenská (kolová a pásová) vozidla a ARC GIS Software. V příspěvku jsou popsány částečné výsledky obranného výzkumu (projektu METEOR a výzkumného záměru VZ FVT 0000401 řízeného Univerzitou obrany v Brně.*

***Keywords:*** *transportation, cross-country movement, geographical factors, natural risks and disasters, cartographic display, Morava, Tišnov, military training area Březina, Czech Republic*

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## 1. Introduction

Geographical support and cartographic visualization is a very important and indispensable element in solution of prediction system and in resolution of elimination of a crisis situation impact.

In the case when we are not able to use some segments on the roads (damaged or destroyed objects, traffic jam etc.), we have to provide a complete analysis of cross-country mobility to solve the transportation problems.

The main terrain elements determining the cross-country movement are relief slopes and microrelief forms. Both the relief parameters and technical parameters of vehicles are important for cross-country passability analyses. These procedures are mostly focused on finding and displaying of the shortest, fastest, or safest route.

Most of materials containing comprehensive methods of cross-country mobility of vehicles are not published due to the professional or commercial secrecy.

Partial (final) data about the relief influence on the cross-country mobility are accessible mostly at several available NATO standardization documents (STANAG), in instructions for practical exercises published by individual NATO geographic services and various professional foreign and Czech bibliographies:

- STANAG 3992 – AGeoP-1 Terrain Analyses (1990) aims at a general evaluation of physical-geographic and socioeconomic elements (relief, vegetation, soils, waters, obstacles, settlement and transport). This document also contains some characteristics of cross--country mobility but does not consider the methods of comprehensive evaluation of cross-country mobility.
- Procedural Guide for Preparation of DMA Cross-Country Movement (CCM) Overlays (1993): This student manual contains directions for data entering to make calculations of cross-country mobility basic degrees. The manual includes neither methodological instructions nor grounds for proceedings how particular numeric parameters were made out.
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- Vala, M. and Rybanský, M. (2001) The impact of relief on the cross-country mobility of selected military vehicles: This essay includes mathematical functions of slope gradient calculations for depiction of terrain profile on the vehicle path, interpolation and regression functions for the formulation of detailed points of terrain profile and the calculation of vehicle running characteristics in terms of cross-country mobility. The essay also contains results of practical tests of the running speed dependence on terrain relief gradients in specific kinds of military vehicles and types of terrain (open terrain, cart way and forest way, road route).
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## 2. Geographic factors of cross-country mobility

Cross-country mobility has a significant impact on rescue operations and military operations in terms of both time and costs. We identify three basic levels of terrain when considering the cross-country movement:
- GO terrain;
- SLOW GO terrain;
- NO GO terrain.

### *Geographic factors affecting the cross-country mobility*

Factors affecting the cross-country mobility and the selection of approach routes (in both positive and negative respects) are especially:
- Slopes of terrain relief;
- Vegetation;
- Surface water features;
- Soil conditions;
- Weather conditions;
- Urban / built-up areas;
- Lines of communication;
- Other natural and man-made features.

The above-mentioned factors interrelate and have a common impact on cross-country mobility expressed by speed deceleration (or by interruption) of movement of certain vehicle phrased by multiple coefficient of deceleration „c“ or by value 0–100% with regard to hypothetically determined optimum conditions of transport - see also Rybansky (2002).

## 3. The impact of relief gradient and microrelief forms on the cross-country mobility

Relief gradient and microrelief forms are factors affecting cross-country mobility of an area because each (with regard to dimensions and technical specifications of vehicles) significant elementary surface has a certain relief gradient and in broad terms also several microrelief forms.

Total resulting coefficient of vehicle deceleration due to relief and microrelief impact is calculated as follows:

$$C_1 = C_{11} \times C_{12} \quad (1)$$

where $C_{11}$ = deceleration coefficient by impact of gradient factor and $C_{12}$ = deceleration coefficient by impact of microrelief factor.

A cross-country mobility and attained terrain speed will be affected not only by relief gradient and terrain microrelief but also by below-mentioned limiting technical parameters of vehicles – see Rybanský (2002).

### *3.1 The impact of relief gradient on the cross-country mobility*

In common sense, a relief gradient is determinable from topographic (finite and per partes plain) surfaces, that are the generalized morphologic picture of Earth surface and that can be implied by using various models of terrain relief. Models ranking among such models are as follows:

- raster model – GRID (quadrate pixel of terrain relief has only one assigned height);
- matrix model (each corner point of square or rectangle is of defined height, it is possible to interpolate heights of intermediate points between the points given);
- triangular model – TIN;
- contour line model has heights in relation to the defining point incumbent on points of intersection of contour surface and terrain relief (height coordinates change parametrically pursuant to contour line distance);
- other models (profile model, hachure model etc).

For the calculation of the terrain relief impact on the vehicle running characteristics it is necessary to know the following parameters:

- profile section traversed by a vehicle and interpolation function for the calculation of detailed profile points;
- vehicle deceleration coefficients of relief gradient impact;
- critical values of slope gradients (for vehicle climbing, swerving motion and rollover);
- other fundamental characteristics of surface (coefficient of rolling resistance, coefficient of static friction etc.) – see also Vala, Rybanský (2001).

#### *Profile section description of vehicle route*

Running conditions of vehicles are largely versatile. The impact of minor surface road roughness is frequently implicated in the coefficient of rolling resistance, which further depends on the size, frequency and shape of these surface roughnesses. If we presuppose a constant transversal terrain profile section of vehicle route, than we can describe that route in space by using length, height and angle dimensions of the terrain Vala, Rybanský (2001), as it is schematically shown in Fig. 1.

This way is fully satisfying only in the description of man-made obstacles made in general by plane surfaces considering the fact that in general the profile of terrain section changes also transversally.

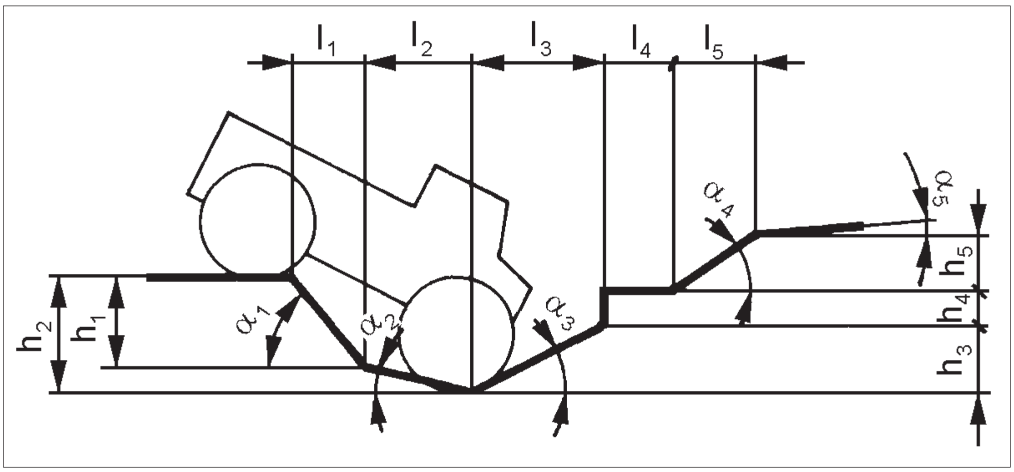



*Fig. 1: Vehicle route description by using length, height and angle dimensions of the terrain*

Another possibility is to divide the terrain area into partial areas and to describe each of them by assigning to it a characteristic value (longitudinal and transversal gradient – α, β, coefficient of rolling resistance – (*f*) and coefficient of static friction – (φ). The smaller these areas will be, the more accurate calculations can be made in respect of vehicle movement, see Fig. 2.

In these elementary areas we can calculate their longitudinal gradient (α) in the direction of vehicle route and also their transversal inclination (β), see Fig. 3.

If we consider a general orientation of the plane in a fixed grid system, then the longitudinal gradient in direction of vehicle route determined from the nearest utmost points of matrix model will be according to Fig. 3

$$\alpha = arc\ tg\left(\frac{z_C - z_B}{x_C - x_B}\right) \quad (2)$$

or

$$\alpha = arc\ sin\left(\frac{z_C - z_B}{BC}\right) \quad (3)$$

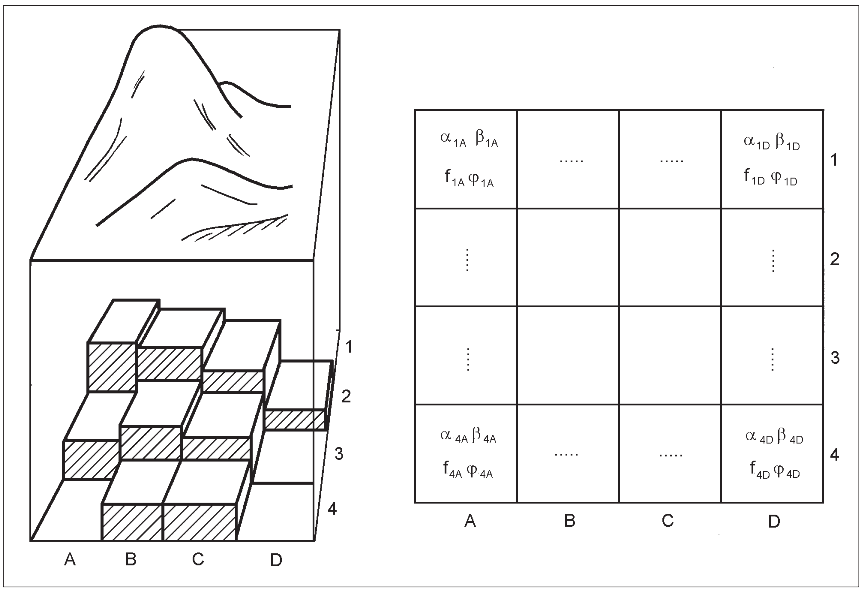



*Fig. 2: Terrain relief characterization by using partial areas*

in the calculation of transversal inclination by using the slant range of vehicle route in the terrain and the truncation of terrain relief roughness between points B and C.

The transversal inclination will be according to Fig. 3

$$\beta = arc\ tg\left(\frac{z_B - z_A}{y_B - y_A}\right) \quad (4)$$

or

$$\beta = arc\ \sin\left(\frac{z_B - z_A}{AB}\right) \quad (5)$$

In the calculation of transversal inclination by using slant range between points A and B.

***The impact of relief gradient on the vehicle deceleration coefficient $C_{11}$***

The coefficient of deceleration of impact of gradient factor $C_{11}$ is determinable on the basis of tractive charts of particular vehicles. A tractive chart (Fig. 4) is the formulation of tractive force dependence on vehicle

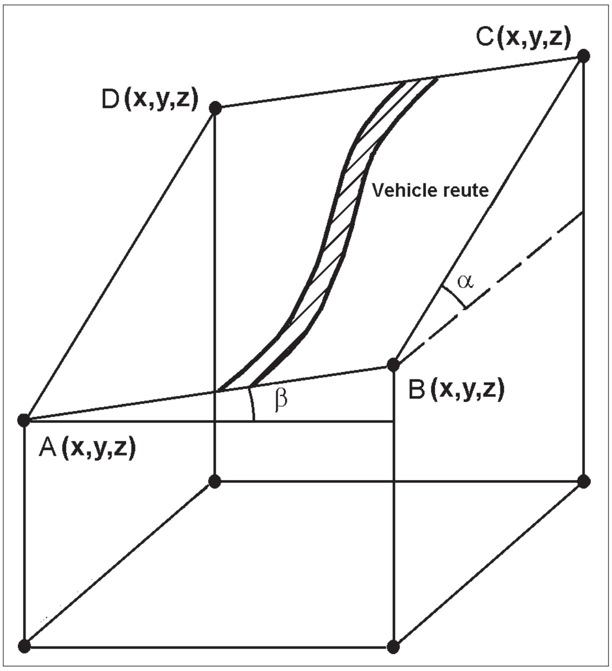



*Fig. 3: Calculation of longitudinal and transversal gradient in vehicle route direction*

driving speed. The driving speed is plotted on the horizontal axis of the chart while the tractive force and the forces of resistance are plotted on the vertical axis of the mentioned chart, $P_m$ is engine performance, $\eta_m$ is mechanical efficiency of transmissions. Coefficient of deceleration $C_{11}$ is equal to proportion between the reduced gradient speed and the maximal road speed. A sample of the tractive chart of road vehicle is shown in Fig. 4.

### *3.2 The impact of microrelief on the cross-country mobility*

The terrain microrelief can be defined as man-made and natural both elevated and recessed topographic forms that cannot be expressed with regard to their relative height differences by use of contour lines or by the means of other principal method of terrain representation. Amongst microrelief forms are in particular:

- slopes (terrain stairs), i.e. rock cliffs, landslides, terraces, embankments and earthworks alongside communications, watercourses and the like;
- ravines, erosion rills and scoured holes of watercourses and storm water, karst lowlands, sink holes;
- rock groups, boulders, talus and stone fields and rows of stones, hillock relief;
- delves, dumps and other forms created by the impact of natural forces (external in particular) and by anthropogenic activities of human society.

#### *Calculation of the coefficient of deceleration due to the impact of microrelief ($C_{12}$)*

Two subjects are viewed by the determination of $C_{12}$:

- limit parameters to assessment of overcoming of microrelief form together with technical parameters of vehicle traffic ability
- length and orientation of microrelief form with regard to vehicle route axis to assess a by-pass trajectory

#### *Determination of the coefficient of vehicle deceleration at overcoming the microrelief*

The essential parameters to the assessment of microrelief forms impact on the cross-country mobility are as follows (Tab. 1):

- slope gradient of microrelief form;
- height of terrain step;
- width of microrelief form, e.g. of scarp, trench, watercourse;
- selected technical parameters of the vehicle.

The value estimation of $C_{12}$ is to be determined on the basis of above-mentioned parameters. The estimation proceeds in this way:

- In microrelief forms No. 1 and 2 (name according to Tab. 1) we have to know at least two evaluation parameters: h, s or α1 (α2), s or α1 (α2), h. The third evaluation parameter is easy deducible by using the below-mentioned functions (see 6).

$$\alpha_i{}^\circ = arctg\,\frac{h}{(s/2)} \quad ; \quad \alpha_i\% = \frac{h}{(s/2)}100 \qquad (6)$$

For the calculation of the pass ability of some microrelief shapes, we must compare the slope gradient values with the vehicle technical parameters. It results from the above-mentioned facts that for particular vehicles and gradients of microrelief forms the values $\alpha_{mez}$ are determinable and these values will indicate specific limits of traffic ability of microrelief form by a vehicle and thus also values of coefficient $C_{12}$ on the basis of under mentioned conditions:

1. $\alpha_i < \alpha_{mez}$ then $C_{12} = 1$;
2. $\alpha_i > \alpha_{mez}$ then $C_{12} = 0$

The first condition and value $C_{12} = 1$ is valid when a microrelief form size is inappreciable comparing with the total length of vehicle route.

In Microrelief forms No. 3, 4, 5, it is sufficient to compare the evaluating parameter h (s) with the parameters of vehicle traffic ability for the determination of $C_{12}$ value.

If the microrelief form has inappreciable dimensions and the time for its overcoming is with regard to overall time of vehicle movement inappreciable, we have to compute the coefficient of vehicle deceleration in compliance with methods described in Chapter 3.1 (The impact of microrelief gradients on the cross-country mobility).

The main microrelief forms displayed on topographic maps and in profile forms are shown in Fig. 5 and 6.

Using the above-mentioned methodology, ARC GIS SW and the digital relief model we created the microrelief and relief coverage of the cross-country mobility map 1:25 000 – CCM 25, see Fig. 7 and 8.

## 4. Conclusions

The cross-country mobility research as a part of terrain analyses is very important, especially during natural disasters and crisis situations, when some road segments and objects can be damaged, destroyed or crowded. In these cases, we have to use special rescue vehicles and to know which terrain areas are passable and which are not in order to secure the rescue personnel, vehicles and to optimize the rescue procedure. The cross-country mobility methodology can be employed in the navigation of terrain rescue vehicles, adapting the procedure for each type of

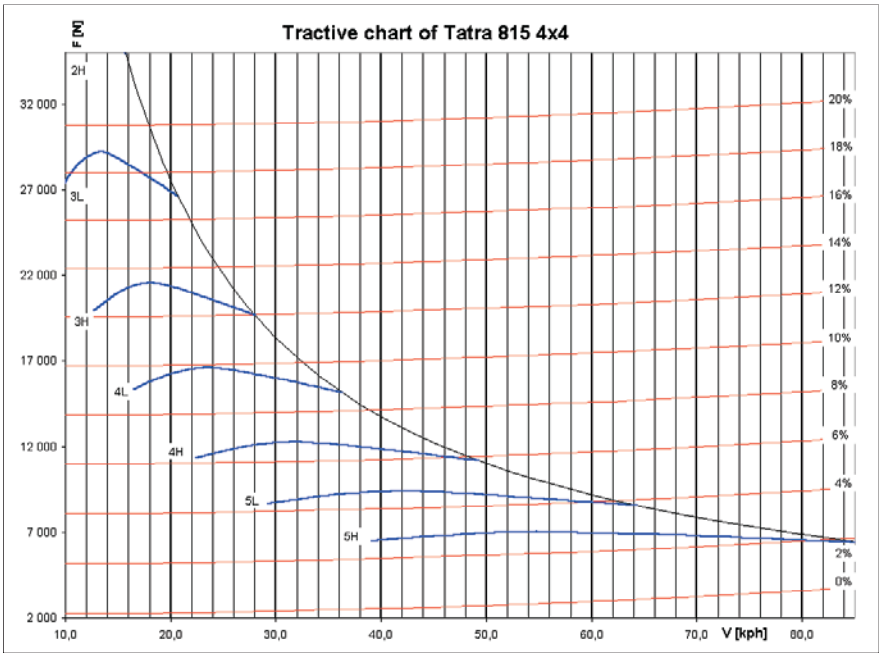
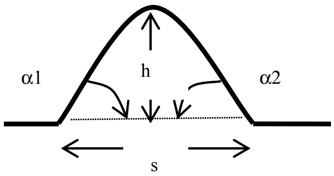
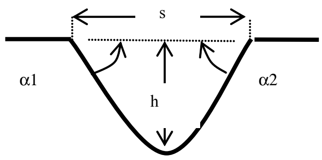
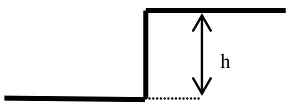
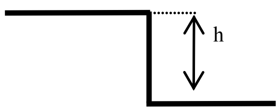
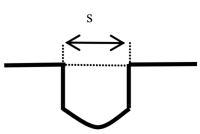



*Fig. 4: Tractive chart of a road vehicle with four-speed gearbox*

| No. | Name | Form design | Evaluating parameters |
|---|---|---|---|
| 1 | embankment |  | - slope gradients (α1 α2)<br>- embankment height (h)<br>- embankment width (s) |
| 2 | Excavation, delve, crater |  | - slope gradients (α1 α2)<br>- excavation depth (h)<br>- excavation width (s) |
| 3 | Terrain step (ascending) |  | - step height (h) |
| 4 | Terrain step (descending) |  | - step height (h) |
| 5 | trench, scarp (crossing) |  | - trench width (s) |

*Tab. 1: Parameters of the evaluation of essential microrelief forms*

vehicle provided that its technical parameters are known. For the future research approach, it will be necessary to create more precise databases with accuracy corresponding to dimensions and other technical parameters of vehicles. Another problem is to link up effectively the cross-country movement digital map with the GPS navigation vehicle system and to train vehicle crews to effectively use these systems.

## 5. Acknowledgements

This paper is a partial output from the defence research project "METEOR" 0801 8 6020R and research programme VZ FVT 0000401 managed by the University of Defence in Brno.

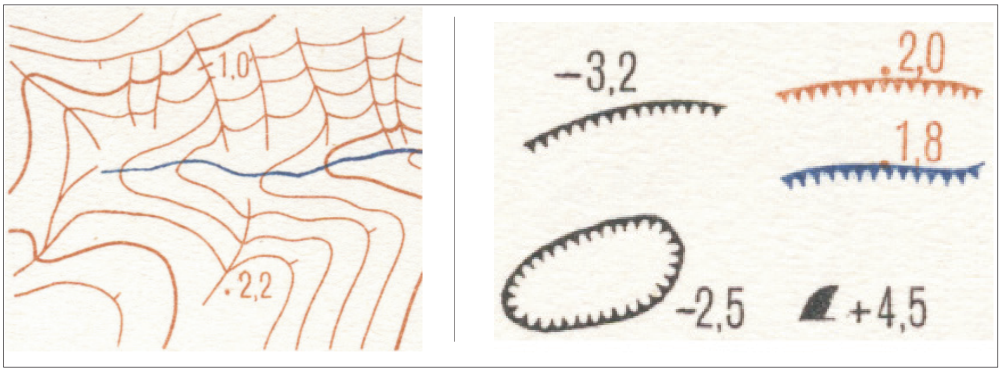



*Fig. 5: Examples of the cartographic symbols of microrelief forms*

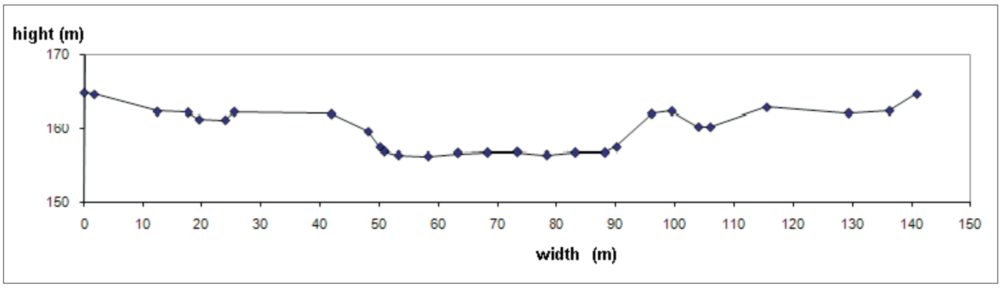



*Fig. 6: Example of the Morava river microrelief profile*

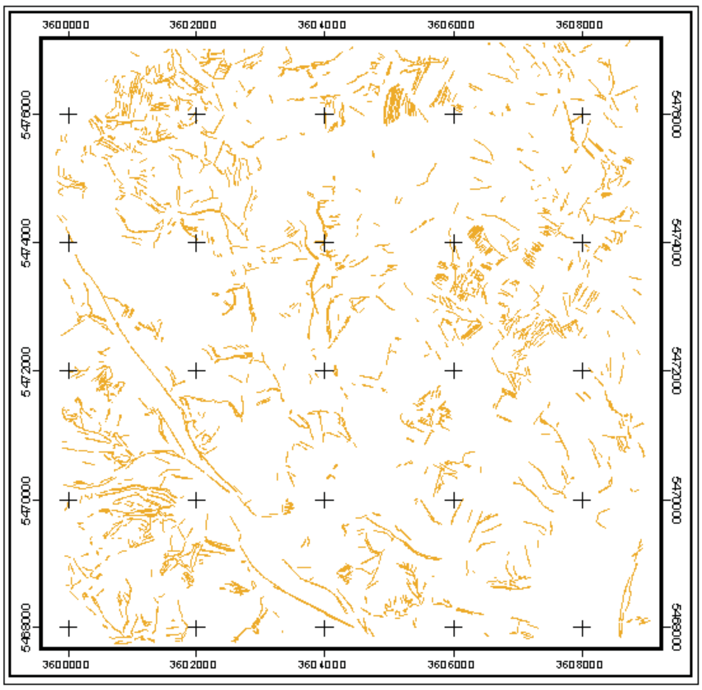



*Fig. 7: Microrelief coverage of the microrelief form (Tišnov area)*

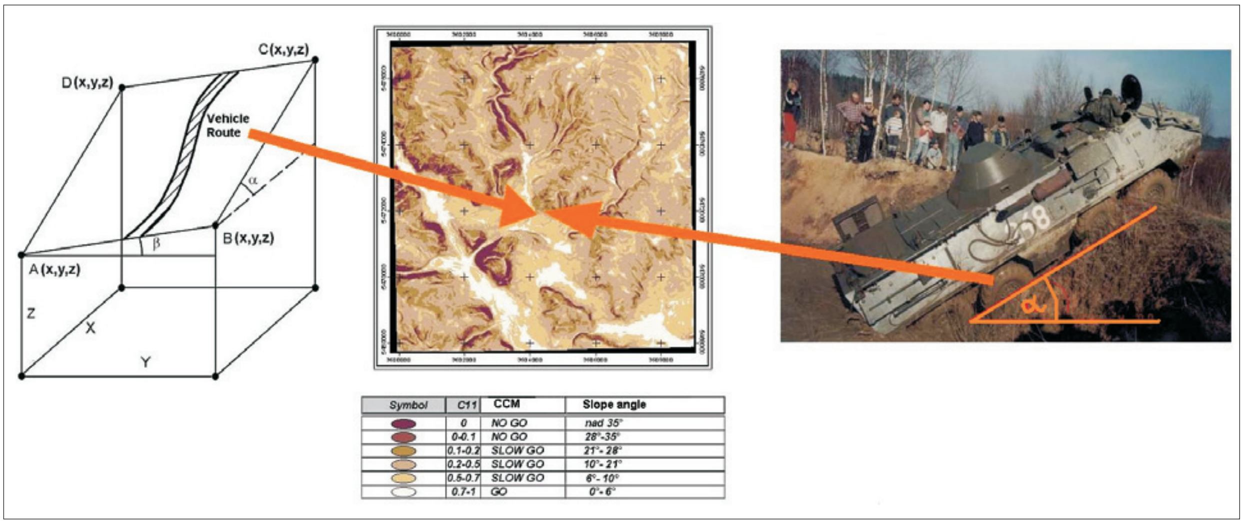



*Fig. 8: Testing and GIS modeling of the slope angle influence on vehicle speed*

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# SHRINKING CITIES IN THE CZECH REPUBLIC? – THE CASE STUDY OF BRNO

Andreas MAAS


### Abstract

*Urban shrinkage represents one of the greatest challenges for present and future European urban development. Population decline, stagnating economic growth and a limited municipal budget are the main dimensions of urban shrinkage that require great involvement with the process to manage its potential effects. Nonetheless no such debate on East Central Europe exists at present. In particular, comparative studies are rare. This case study of Brno investigates whether shrinkage is a problem in the Czech Republic and whether the concept of shrinking cities is applicable. An indicator approach is developed in order to provide an instrument or basis for international comparison.*

### Shrnutí

### Zmenšují se města v České republice? – Případová studie Brno

*Zmenšování měst představuje pro současný i budoucí urbanistický rozvoj v Evropě jeden z největších problémů. Klesající počet obyvatel, stagnující hospodářský růst a omezený obecní rozpočet jsou hlavními aspekty zmenšování měst; to vše vyžaduje vysokou angažovanost v procesu řízení jejich potenciálních důsledků. Diskusní platforma k tomuto jevu však dosud ve východní části střední Evropy neexistuje. Zejména srovnávací studie jsou vzácné. Na případové studii Brno jsme se pokusili zjistit, zda i v České republice dochází ke zmenšování měst a zda koncept „zmenšujících se měst" je aplikovatelný i pro Českou republiku. Byl vypracován koncept indikátorového přístupu jako nástroje pro možné mezinárodní srovnání.*


**Keywords:** *shrinking city, economic restructuring, municipal budget, post-socialist transition, Brno, Czech Republic*

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## 1. Introduction

Since the mid-1990s, urban shrinkage has been growing more popular as a field of research. One region in focus, due to the dramatic effects of the process, is eastern Germany. Nevertheless, similar debates also exist in Great Britain and North America. In contrast, there is little attention on the debate in East Central Europe. Two Czech exceptions are Andrle (2001) who found "demographic stagnation" in the major Czech cities and Tvrdík (2007) who states that some cities are going through an "era of reduction". Nevertheless, particularly in Poland and the Czech Republic a lack of research is still visible in the field of urban shrinkage (Steinführer, Haase, 2009). If we look at similar developments in Eastern Germany and the Czech Republic since 1989, but also at the differences, an intensification of the debate should result in a gain of knowledge.

Moreover, it is a comparative approach that is missing. Exceptions are studies focusing on the population development of Mykhnenko and Turok (2007), Ciesla (2008) or Brade and Smigiel (2008). In this paper, urban shrinkage is understood more broadly, including the economic and financial frame in addition to the demographic dimension. The results of a degree thesis, linked to "conDENSE", an international project, coordinated by the Helmholtz Centre for Environmental Research in Leipzig, includes partners and case studies from Poland and the Czech Republic.

Based on German experience, the aim of the study was to show that there are shrinking cities within the Czech Republic. Hence, the concept of shrinkage could be adapted to the Czech Republic. This paper makes clear that it is not as easy to say that Brno is a mid-term shrinking city, because of its declining population since the 1990s (Mykhnenko, Turok, 2007). Other aspects of city development such as economic stagnation or a limited municipal budget and different data sources must also be observed. Furthermore, it becomes apparent, that in spite of a similar urban history (post-socialist transition, demographic change), different developments exist between eastern Germany and the Czech Republic. In addition, this paper points out different developments within the city and between different fields of urban development.

## 2. The debate on shrinking cities and a definition of urban shrinkage

The existing approaches to the issues of urban shrinkage or shrinking cities vary. In the global debate, more or less three different regions and related topics emerge.

In North America, the discussion is mostly centred on decline or decay in the inner city and since recent years even about shrinking (Beauregard, 2003). Here the shrinking cities group in Berkeley should be mentioned. Shrinking populations were observed as a result of economic decline, structural change or suburbanisation (Pallagst, 2005). It is evident that urban planners or decision makers are advocates of the growth paradigm. Shrinkage as a direction for urban development is more or less taboo (Pallagst, 2006). The general aim is to resolve economic decline and decay through renewal or development strategies for inner cities. Typical cities for the North American discussion are Detroit, Chicago or other former industrial cities located in the so-called "rust belt".

In Great Britain, the term "decline" is mostly used and indeed the discussion there predominantly focuses on economic decline. There is a concentration on the former mining and mono-industrial regions with their structural problems. In connection with the effects on employment and the structure of buildings, the resulting social problems are mentioned. Some examples of these are social exclusion and poor living conditions within or for the population. The decline of inhabitants is a consequence of the economic frame. A good overview about the British debate is provided by Lang (2005).

In the West German debate, the term "shrinking city" was first used by Göb (1977) but is well known from Häußermann and Siebel (1988). They discuss the loss of size, density and urbanity in shrinking cities. The resulting disputes have different focuses. One of these concentrates on the development of cities or regions, which are affected by structural change and its effects and can be compared with the Anglo-American debates. A typical example of this is the Ruhr area in western Germany.

The "West German" debate about "shrinking" was forgotten during the economic boom period in the early 1990s. At that time, many West German cities with previously poor development started growing again because of the in-migration from East Germany and the former Soviet Union (resettlers or "Spätaussiedler"). In the late 1990s, the urban shrinking debate was revived in connection with the unintended consequences of the post-socialist transition in eastern Germany and the developments within eastern German cities. In addition to industrial and structural decline in the economy, a massive loss of jobs and an increase in unemployment, population decline became more and more apparent, not lastly due to the out-migration to western Germany, the death surplus and suburbanisation, all of which had effects in a new dimension. In more recent discussions, authors therefore focus on the demographic dimension (cf. Herfert, 2007).

The Czech dispute is limited on "demographic stagnation" or "era of reduction"(Andrle, 2001; Tvrdík, 2007). Großmann et al. (2008) discuss the transferability of the German shrinkage concept to other post socialist countries (e.g. Czech Republic) and differences to the Anglo-American debates in more detail. It should be pointed out, that in contrast to the terms of "decline" and "decay" the term "shrinkage" has a less negative connotation. Generally urban shrinkage could be understood as a reduction of the extent or the size of objects or their quantity (Lang, Tenz, 2003), but cities are not reduced in size. Häußermann and Siebel (1988) speak about a decrease in the density and the urbanity of a city.

In this paper, "(urban) shrinkage" is used to describe a multidimensional process. The main dimensions of urban shrinkage are demography, economy and finance. Hence, a shrinking city with a more or less constant area is characterised by decreasing population, by economy that is not developing as well as it was and by municipal budget that has become worse. These factors lead to a fall in the density of use within the city border and less diversity.

The following chapter discusses causes and effects of urban shrinkage and its sub processes. Shrinkage could be included in a larger research context, but until now, no "Shrinkage Theory" as such exists.

## 3. Causes of urban shrinkage

Shrinkage as one path of urban development is no new phenomenon. In the history, several causes for the shrinkage of cities or towns can be found. Benke (2005) merges the reasons into seven common groups:

- Urban disaster: e.g. fire, epidemics, wars
- Changes to the environment: e.g. the silting of docks or harbours

- Collapse of the economy or public order: e.g. a change of political system, political transformation, economic and political crises
- Economic decline: e.g. changes in demand, shift of trade routes, competition, loss of the market and distribution area
- Loss of centrality and functionality: e.g. isolation during railway construction, shift of administrative centres, political disempowerment of cities and population groups
- Internally created crisis: e.g. opposition to modernization such as boycotting the establishment of a local railway station
- Loss of small scale functions for the hinterland: e.g. new demarcations after wars

This list of causes is not exhaustive, but it gives a good overview (cf. also Rieniets, 2004; Oswalt, Rieniets, 2006). It points out that shrinkage was a development option for cities besides growth. Today's society does not accept this fact, because industrialisation of the 19th and 20th century was predominantly characterised by growing and expanding cities and economies (Benke, 2005; Oswalt, 2004). Therefore, it is difficult for urban planners, developers and administrative bodies to leave the path of the growth paradigm and to think in dimension other than growth (Großmann, 2007). Today's situation and the number of shrinking cities differ from history. Population decline now exists in more cities and over a longer period and that in times of relative prosperity and wealth (Rieniets, 2004).

With regard to the regional focus of the Czech Republic in general and of Brno in particular, and also to the period in focus since 1991 – i.e. more or less the era of post-socialist transition – there is a frame of main causes for possible urban shrinkage developments and population decline. The political change in 1989/90, the transformation processes as well as rising globalisation and Europeanization induced decisive modifications within the Czech corporate landscape. Results, after the first booming years, were growing unemployment and a decreasing number of employees. Old industrialized areas were hit particularly badly. The growing tertiary sector could not compensate for the loss of jobs from industry in these regions (Mayer, 2002). The decreasing number of industrial jobs resulted from the downsizing of companies or insolvency proceedings. At first the Czech Republic was opportunistically recognized for its cheap labour force and good infrastructure, but in recent years, the shift of some companies to even cheaper countries was visible, for example Flextronics (Mulíček, 2004).

In the field of demography, the demographic change or the second demographic transition (Lesthaeghe, 1995; Van de Kaa, 2004) is visible as a reduction in the number of births. In fact, in the 1990s the Czech Republic belonged to the countries with Lowest-Low-Fertility (Kohler et al., 2002). Natural population development was negative, i.e. more people died than were born. In the field of migration, another development was visible. At the time where the Czech Republic was still Czechoslovakia, the largest cities were characterized by in-migration. This process was turned around in the 1990s with the net migration becoming negative. Towards the end of the 1990s, the process of suburbanisation intensified. Besides shopping centres and business parks in suburbia, settlements of detached family houses mushroomed on open green spaces (Maier, 2001).

Summing up, political transformation and the structural change of the economy, demographic change as well as suburbanisation are the main causes for possible urban shrinkage in the Czech Republic and in the case study of Brno. The processes mentioned affect a reduction in the density of use in cities. These and other effects will be described in the following chapter.

## 4. Consequences of urban shrinkage

Demographic and economic shrinkage have direct and indirect, as well as negative and positive consequences. The main effects of the shrinking process are a fall in the demand for and sometimes an increasing vacancy of buildings and land parcels. Due to a fall in demand, secondary and tertiary sector buildings or land parcels lie idle and habitat density falls (Friedrich et al., 2003; Gatzweiler et al., 2003).

In addition, the declining population causes a reduced demand for dwellings (Albers, 2005; Birg, 2004). The increase in living space per person and the increasing number of single households could partially compensate for the fall in demand (Winkel, 2003a; ČSÚ, 2003). Eastern Germany is an extreme case. Here the massive number of vacant dwellings is caused by a fall in the population in connection with other arrangements such as subsidies for reconstruction and new buildings (Bernt, Peter, 2005) and has very different effects. Vacant properties, low demand and the joint profitability loss entail lower reconstruction activity and the decay of buildings (Killisch, Siedhoff, 2005). The rising number of brownfields and idle buildings could have positive future impacts. For example, the cheap availability of areas could be a magnet for new companies in comparison with other cities. Through lower housing density and existing brownfields, there is an opportunity to improve the housing and living conditions through spaces or parks. On the one hand, the fall in demand and an increase in vacant properties brought about disadvantages and losses to the supplier. On the other hand, the options and rent level are improved for the tenants and consumers. In eastern Germany a supply surplus is visible (Albers, 2005), which affords an increasing intra-urban mobility.

Intra-urban mobility occurs selectively within the city, similar to suburbanisation. This means that employees and people with a higher income could afford to move to qualitatively higher and hence more expensive city quarters, whereas the unemployed or poor people are forced to stay. This socio-economic exclusion strengthens segregation or growing social combustion points and fragments or polarizes into loser and winner areas (Lötscher, 2005; Piniek, Prey, 2005).

A fall in the population in the neighbourhoods as well as the closing and the shift of industrial companies to other countries could affect an under-utilization of the pipeline-bound technical infrastructure (Albers, 2005; BBR, 2006). If the minimum flow falls below a critical point, the operability is no longer ensured (Koziol, Walther, 2006) incurring further costs. However, there are additional costs and problems before the technical infrastructure will collapse. The decreasing number of users and consumers already results in a lower income (Koziol, Walther, 2006), which also means that variable costs decrease whereas fix costs persist. Finally, the costs per person increase, resulting in higher fees (Winkel, 2003a). The lagged adjustment of variable costs also exists for administrative bodies (Killisch, Siedhoff, 2005).

The problem of capacity utilization also exists in the field of social and cultural infrastructure such as schools, doctors and cinemas. The capacity utilization decreases due to a fall in the number of users, whereas the fix costs remain almost constant. The variable costs shrink parallel to the income. Hence, the admission price is increased so that the facilities do not have to be closed (BBR, 2006; Bernt, Peter, 2005; Birg, 2004). Some public institutions have to exist however in order to supply the primary needs of the population (i.e. hospitals, schools), despite their under--utilization. Such unprofitable facilities put a strain on the municipal budget. Another problem of shrinking cities is the loss of quality of life, if the social and technical infrastructure is lacking or other facilities are lost (Killisch, Siedhoff, 2005). In connection with the demographic change, the demand for specialist doctors, leisure facilities and the supply for senior citizens changes (Bernt, Peter, 2005; Winkel, 2003a). To sum up, the demand for infrastructure changes both qualitatively and quantitatively.

An indirect negative consequence of the decreasing density with the supply of social and cultural infrastructure is a fading or disappearing identification with the neighbourhood (BBR, 2006). Additionally, the distance travelled to reach such amenities becomes greater (Albers, 2005). Furthermore, suburbanisation induces an increasing rate of commuters (Friedrich et al., 2003). These two trends and the increasing number of cars per person since the beginning of the 1990s cause a surplus load for main roads. The traffic infrastructure has to be reconstructed or developed. By contrast, the infrastructure is used less within neighbourhoods with a decreasing population or vacant properties. The municipality is confronted with a financial surplus load.

In addition to the economic consequences of deindustrialization or "deeconomization" (Hannemann, 2004), which result from political transformation processes and globalization tendencies, shrinkage affects the economy both directly and indirectly. On the one hand, the loss of cooperation partners, suppliers and consumers of products and services should be mentioned as a direct effect. On the other hand, the population loss and therewith a reduction of consumers brings about a fall in the demand for goods or services of local companies (Bernt, Peter, 2005; Rosenfeld, 2003). Furthermore, there is a lower propensity to spend per capita because of the rising prices for infrastructure (public transport, additional living expenses) and the increasing tax burden (the disparity between the payer and the beneficiary) (Winkel, 2003b). These points pressurise local companies (retail) even more because of the decline in sales.

The demographic change and the transformed age structure not only entail a change in demand. An additional but often forgotten consequence of the shrinkage and ageing of the population are a decreasing labour force and human resources (Rosenfeld, 2003; Winkel, 2003a). Qualified employees migrate into regions, which have better economic growth and the rate of regeneration of the labour force in the companies decreases, resulting in less innovation (Kaufmann, 2005).

As several authors (Bernt, Peter, 2005; Killisch, Siedhoff, 2005) have already mentioned, one of the main consequences of urban shrinkage is a worsening financial situation of the municipality. The tax income decreases through declining economic power and population. Furthermore, increasing expenditures determine a worsening of the municipal budget and a primary supply must be guaranteed (Bernt, Peter, 2005) in spite of a reduction in the technical, social and cultural infrastructure. In addition to this, a third financial consequence of population decline comes along: the allocation of state funds according to a certain key for municipalities to ensure services (hospitals, administration, court) for the urban hinterland decreases (Killisch, Siedhoff, 2005). Another effect of a worsening municipal budget is the decreasing possibility to regulate or control the situation through financial support (Piniek, 2005; Pohlan, Wixforth, 2005). From the point of view of spatial planning, urban shrinkage induces a cultural and economic differentiation and a change in position in the settlement system (Benke, 2005).

Strong shrinkage processes could result in downward spirals or strings of shrinkage, as is shown in Fig. 1. These spirals or strings act cumulatively on the whole shrinkage process.

Table 1 concludes the effects mentioned on the shrinkage process in a list. Additionally, a classification of different consequences into direct and indirect ones as well as positive and negative ones is made. This table is not exhaustive and the statements are of a hypothetical nature and only partially proven. The examples given are taken from Germany because of the non-existing Czech debate on urban shrinkage.

By way of conclusion, one can say that the connotation of shrinkage is predominantly negative. This is visible in the majority of negative effects of urban shrinkage (Tab. 1). Shrinking cities often have, compared with decline and decay, a negative image. The image could affect the future development of the municipality negatively (Steinführer, Kabisch, 2005).

## 5. Methodology and Methods

This study aims to answer the question of whether the concept of urban shrinkage or shrinking cities can be adopted in the Czech frame. If shrinking cities exist within the Czech Republic, then this field of research requires more attention.

To assure comparability with other studies, this paper analyses the urban development within the administrative boundaries referring to Oswalt and Rieniets classification (eds., 2006). I'm aware of the varying definitions of administrative urban borders in different countries and even between different cities. In this regard, it must be mentioned that it is very difficult to scope the city from its hinterland. On the other hand, statistical data exist only on the level of administrative units like cities or municipalities and not on the level of for example a functional urban region. A third point is that a municipality can only intervene or influence developments within its administrative border.

Often, in East Central Europe, the urban development at the time elapsed is represented by a comparison between two census data sets (Andrle, 2001; Mulíček, 2004). Between the two censuses, the developments are hypothesised as linear. In the case study of Brno, annual data are used to illustrate the processes since 1991 in a "real" longitudinal cut. The temporal resolution shows developments in more detail compared to only the comparison between two censuses (1991–2001).

In order to answer the research question as to whether Brno is a shrinking city or not, quantitative statistical data were analysed with the help of an indicator approach for the period in focus from 1991 to 2006. Qualitative statements from expert interviews with members of the city administration and research institutes were used in addition and explain the whole frame and processes in more detail. The indicator approach is based on the method of Gatzweiler

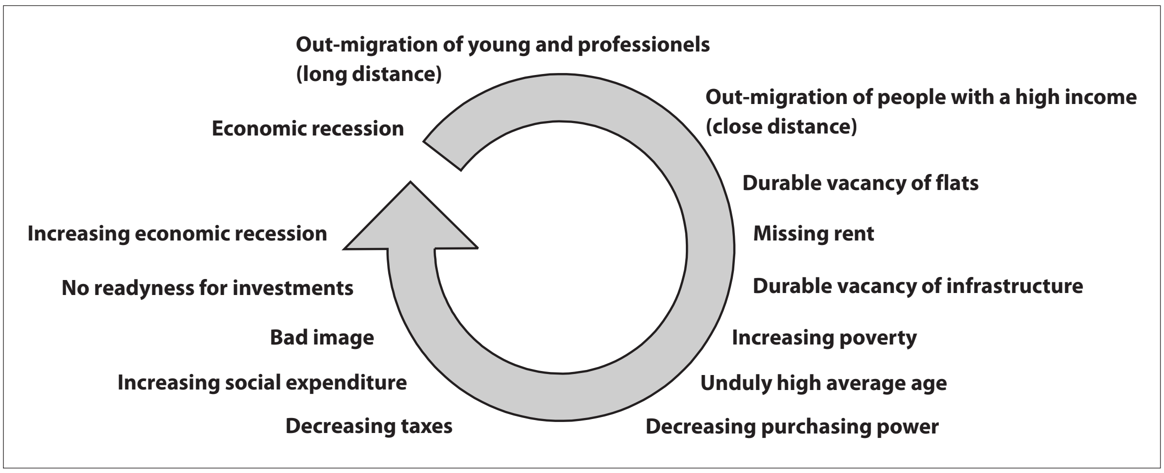


*Fig. 1: Downward spiral due to shrinkage*
*(source: Ingeborg Beer in Hannemann, 2003)*

| Effect | Cause | Direct / Indirect | Positive / Negative |
|---|---|---|---|
| Decreasing demand (qualitative / quantitative Change) for land parcels, buildings, dwellings, infrastructure (social / technical / cultural), (local) products /facilities | Deindustrialisation / Deeconomisation, Depopulation, Demographic change | D | N-supplier<br>P-consumer |
| Decreasing price / rent of land parcels /buildings / dwellings | Decreasing/ changing demand | I | N-supplier<br>P-consumer |
| Rising prices for infrastructure / consumption of local products / facilities per person, increasing tax burden per person, stagnation of / decreasing purchasing power | Deeconomisation, Depopulation, Decreasing demand, worsening municipal budget | D<br>I | N |
| Decreasing profitability, additional costs for licensee / tenant, lower income, lower (re)construction activity | Decreasing demand, under-utilisation | I | N |
| Loss of social surroundings / networks, increasing fragmentation or polarisation (of quarters) /segregation | Depopulation, (Deeconomisation) | D | N |
| Possible under-utilisation / collapse of pipeline-bound technical infrastructure / social infrastructure but surplus load of traffic infrastructure (main roads) | Suburbanisation, Depopulation, Deeconomisation, decreasing/ changing demand, | D | N |
| CI (but primary needs must be ensured) | Depopulation, Deeconomisation, decreasing / hanging demand | D | N |
| Prolonged journey / travel time to facilities / infrastructure | CI, suburbanisation | I<br>(D) | N |
| Growing decay of buildings, rising number of brown fields / idle buildings | Depopulation, deeconomisation, CI, lower reconstruction activity | D<br>I | N |
| More green spaces / parks / “nature” | More brownfields, demolition of buildings | I | P |
| Decreasing degree of utilisation within the city | Depopulation, deeconomisation, CI | D | N/P |
| Increase in living space per person, possibility to improve housing / living conditions (space per person, green space) / rising location quality | Depopulation, decreasing demand, more green spaces | D<br>I | P |
| Loss of location quality | Increased distance to or complete CI, loss of social networks, depopulation | I<br>D | N |
| Fading / disappearing of identification with neighbourhood | Loss of social networks, CI, loss of location quality | I | N |
| Decreasing LF, reduced number of qualified workers, less innovations, lower regeneration of the LF | Depopulation, demographic change, closure of educational infrastructure | D<br>I | N |
| Strengthened pressure on (local) companies, loss of workplaces, insolvency | Decreasing LF / demand / loss of partners, CI | I | N |
| Loss of cooperation partners / suppliers, consumers | De-economisation, deindustrialisation, depopulation, strengthened pressure on local companies | D<br>(I) | N |
| Worse situation of municipal budget (decreasing tax income, rising / constant costs) | Depopulation, de-economisation, preservation of infrastructure for primary needs | D<br>I | N |
| Reduced possibility to regulate/ control situation (e.g. financial support) | Worse situation of municipal budget | I | N |
| Changing position in settlement system / centrality / building structure, cultural / economic differentiation | Depopulation, de-economisation, CI | D | N/P |
| Negative image | Depopulation, de-economisation, CI, financial problems | D/I | N |
| Downward spiral | All mentioned problems combined | D/I | N |

*Tab. 1: Classification of the effects of urban shrinkage in connection with causes*
*Note: LF - labour force, CI - closure of infrastructure*

et al. (2003) used for Germany. He worked with six indicators to operationalise the development of the cities within the fields of demography, economy and finance. This is displayed in Fig. 2. If the majority of the indicators are negative (exception: rising unemployment rate), the city is considered to be a shrinking city.

The approach was modified according to the Czech Republic and the city of Brno as well as the available statistical data. The indicator "number of employees" substitutes that of "number of jobs" and the "balance of municipal budget" replaces the German Realsteuerkraft ("municipal tax income"), which resulted from the different municipal tax and distribution system in the Czech Republic. The balance of the municipal budget shows the financial and regulation problems more clearly than the "Realsteuerkraft" does. The development of the number of jobs differs from the development of the number of employees, too, but it indicates the economic development as well as the development of the number of jobs. Unfortunately, data on purchasing power do not exist in the Czech Republic on the level of the municipalities and could not be substituted by a comparable indicator. Hence no statements about the development of the financial budget of the inhabitants could be given.

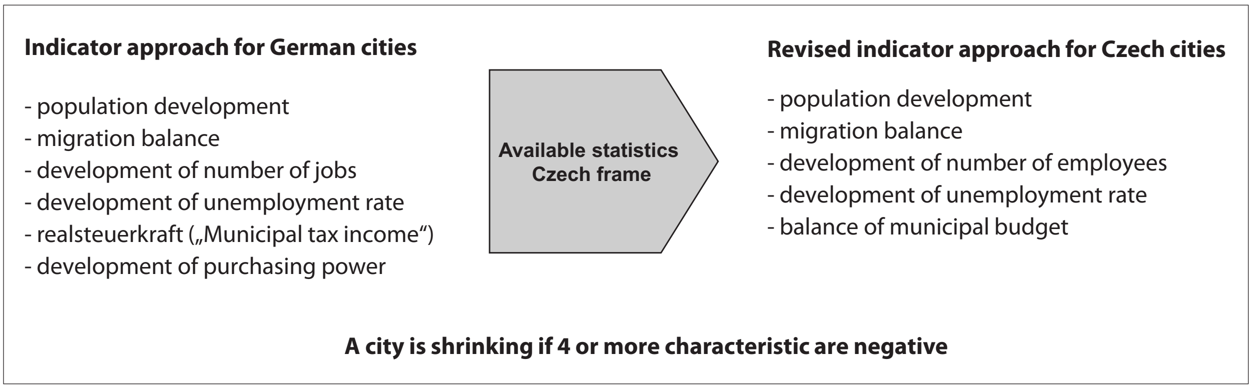


*Fig. 2: German and Czech indicator approach (source: Gatzweiler et al., 2003, author)*

The investigated city will be considered a shrinking city if at least four indicators show negative developments. Fig. 3 makes this clear. Because of the missing indicator "purchasing power" as an indicator on the one hand, and or because of missing data over some years (2006) on the other, a definite statement for or against shrinking is not possible when three indicators display shrinkage.

This study focuses on the period 1991–2006. In 1991, a census took place in the Czech Republic, providing a relatively good statistical starting point. Subsequently, the regional and municipal statistics were aligned. Furthermore, 1991 was relatively close to the beginning of the post socialist transition in 1989/90. For every year indicators are available (per 31/12), but only on the level of the whole city. Additionally, a further census took place in 2001. In addition to the annual data, both censuses enabled a more detailed look at the developments within the city on the level of cadastral units and developments.

The data are based on different sources with the central source from the Czech Statistical Office (ČSÚ, 2007a,b), which provides data on all indicators except for the municipal budget. Over the period in focus, the method for determining the unemployment rate changed in 2004, although this did not influence the general trend. As for the statistical series for the number of employees, there have been even more changes, therefore only the developments within the periods of use of a specific method are comparable. Every change in method brings along an increase in the number of employees. Over the different "method-periods", the trend of the development of the number of employees did not change, except over the last period from 2002. The author calculated the balance of the municipal budget from that date for expenditures and income provided by the municipality of Brno (MMB, 2007). The five indicators of that data form data-set 1.

In addition to the data sources mentioned, two other sources exist. These show a varying picture of the developments. Firstly, data from the Centre for Regional Development of Masaryk University (VCRR MU, 2005) on the number of employees could be used. This data series additionally allows a view on the development of employees in the tertiary and secondary sectors. The number of employees according to this study is

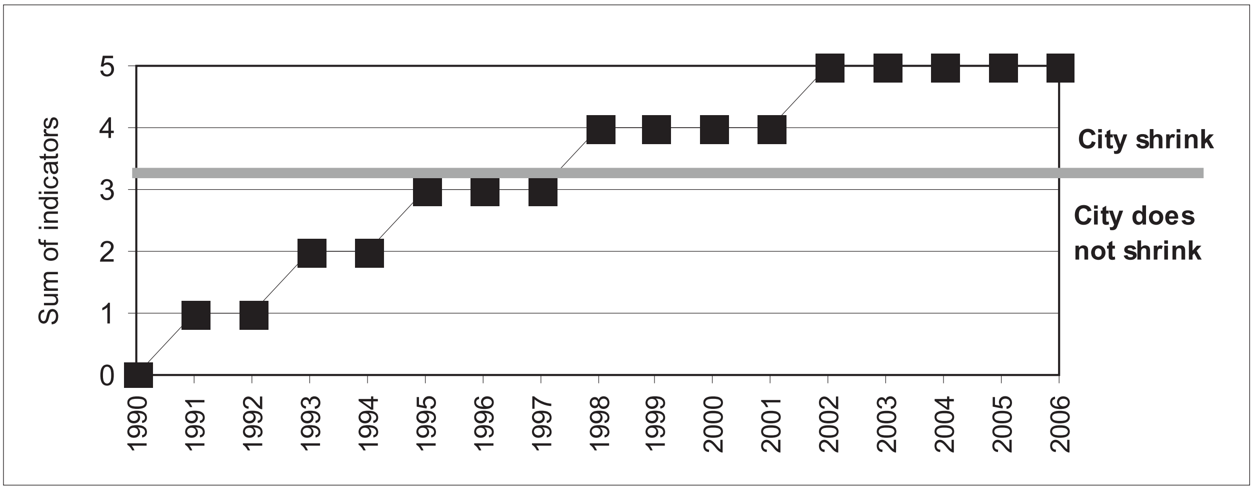


*Fig. 3: Example of (hypothetical) shrinkage assessments (source: author)*

always higher than the one provided by the ČSÚ due to a slightly different method of determination. The study has a local focus and also considers smaller companies compared to the ČSÚ method. As for the population since 2003, data from the Ministry of Interior of the Czech Republic (MV CR, 2008; ISEO registry) are available. These data also vary from the ČSÚ data, due to a different methodology. ISEO shows a higher number of inhabitants and a more positive trend (Kabisch et al., 2008).

Data-set 2 is compiled from 5 indicators from a combination of data sources. In contrast to data-set 1, the number of employees is from VCRR MU (2005) and the population development since 2004 is calculated from the date of the ISEO database. The other indicators are from the same source as data-set 1.

## 6. The Case Study of Brno

The city of Brno was chosen for this study because of four facts. Firstly, Brno is a second order city, which means that it is an important city in the Czech urban system but not the capital. It is therefore more comparable with the development of other medium-sized Czech cities. Secondly, Brno is a municipality and at the same time a district where (as a third fact) no incorporation took place over the focus period. Furthermore, through former cooperations, contacts to research facilities in and to the magistrate of Brno exist.

Brno is the second largest city in the Czech Republic with almost 370,000 inhabitants and an area of 230 km. As the regional capital of South Moravia, it serves as a supra-regional centre of administration and justice of the Czech Republic. Formerly Brno was an industrial centre that specialised in textiles, and later on engineering and electro-techniques. Over the past 20 years, the tertiary sector has also gained significance. Today Brno is the most important location for trade fairs and exhibitions in East Central Europe. Within the context of population and housing market developments, another important feature is Brno's function as a centre of education, science and research. Five state universities and more than 65,000 students (2006) show the importance of this factor for the city.

Below, the developments of the population, economy and municipal budget will be shown by the five indicators mentioned above for the period in focus 1991–2006. As a result, the question as to whether Brno is a shrinking city or not can be answered. Subsequently, a discussion will follow in chapter 7.

### *Demography (indicator population development and migration balance)*

At first, it should be mentioned that the population of Brno increased until 1993, as Fig. 4 shows. Since the year 1994, the number of inhabitants has been decreasing (Indicator population development). The continuous decrease brought about the lowest level of 366,680 inhabitants at the end of the year 2006 (ČSÚ, 2007a). Since 1983, the number of births has been permanently lower than the number of deaths. In contrast, the indicator migration balance varies with more short-term fluctuations than the negative natural population development between 1983 and 2005. In the first third of the focus period (until 1995), Brno features a positive net migration, because the city is characterised by in-migration. After 1995 until the end of the focus period, out-migration prevails.

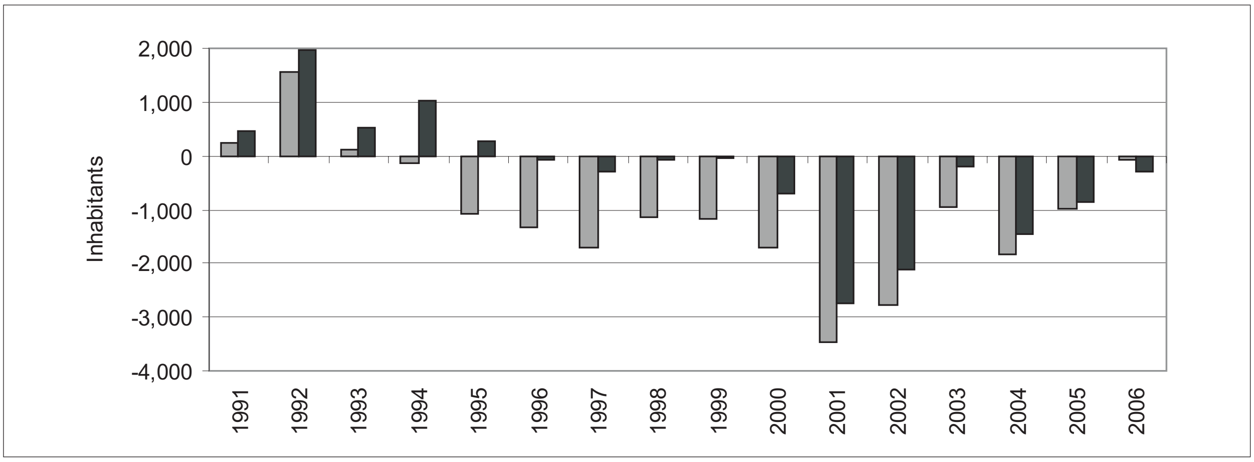


*Fig. 4: Demographic development*
*(source: ČSÚ, 2007a)*

### *Economy (indicator number of employees and unemployment rate)*

In the field of the economy, different phases of development are visible, compared to the development in the whole of the Czech Republic. In Brno, the primarily low unemployment rate of less than 2% has increased since 1996, with the maximum being reached in 2003 with nearly 11%. Since 2004 the situation on the labour market has been improving and the unemployment rate continued to decrease until 2006 (Fig. 5). An examination of the development of the number of employees is more complicated.

As mentioned in Chapter 5, modifications to the data--collecting method took place within the period in focus and the existing time series of the ČSÚ, although it can be assumed, that the number of registered employees decreased between 1991 and 2004. Since 2005, the economic boom in the Czech Republic and the growth of the number of employees are visible.

### *Municipal Budget (indicator balance of the municipal budget)*

After a negative balance of the city budget in 1991, a period of positive development followed until 1999. Brno generated more expenditure than revenue in the period between 2000 and 2004 (Fig. 6). In the following year, a positive financial balance was visible, which decreased slightly in 2006.

### *Results*

The overall examination of the five indicators identifies Brno as being a shrinking city between the years 1996 and 2004 (Fig. 7). During this period, at least four indicators showed a negative tendency. Over the period in focus, there are three years (1992, 1993 and 2005) in which Brno did not shrink. Due to the explanations given in section 5 above, no clear statement was possible for the other years. Thus, the city of Brno as administrative unit was marked by a nine-year lasting shrinking period that ended in 2004.

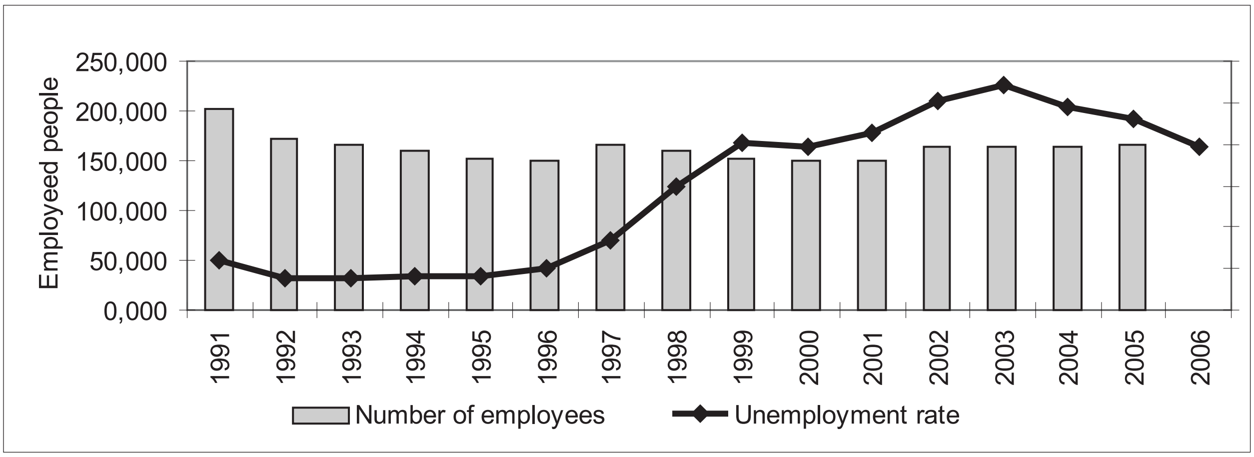


*Fig. 5: Economic Development*
*(source ČSÚ 2007b; number of employees not available in 2006)*

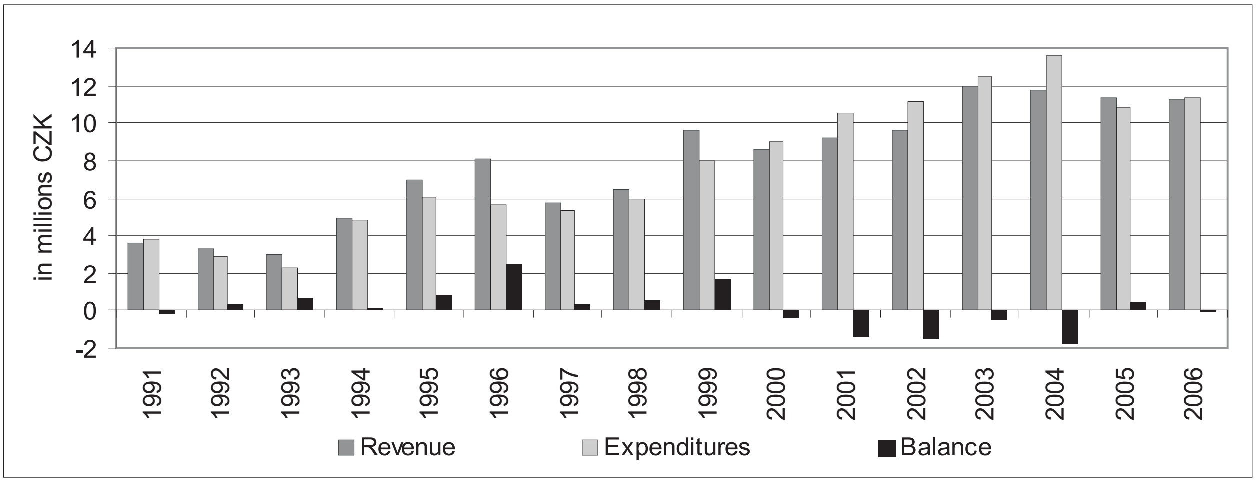


*Fig. 6: Municipal Budget*
*(source: MMB Brno, 2007)*

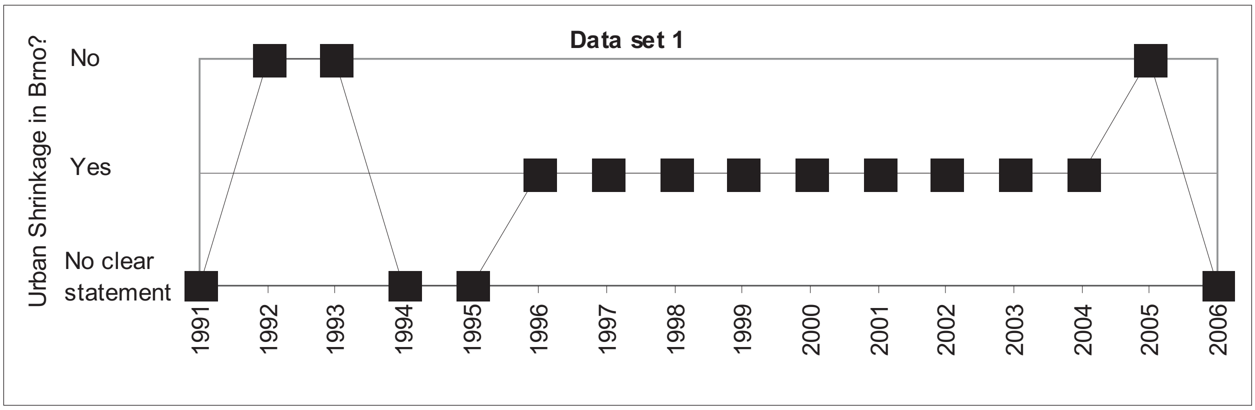


*Fig. 7: Shrinkage assessment for the City of Brno 1991–2006*
*(source: author's calculation, Data ČSÚ, 2007a,b)*

## 7. Discussion

The shrinking period of the city of Brno within the period of focus can easily be explained by the economic recession in the Czech Republic. The long-term negative natural population development (a deficit of births) and the start of suburbanisation, including the out-migration of inhabitants and companies to the hinterland, should be added. In 2000, suburbanisation intensified. The positive development that can be observed since 2005 can also be explained due to the fact that the national and local economy started to grow and the big birth cohorts of the 1970s and 1980s reached the age of reproduction. These cohorts have led to a birth surplus since 2006, which even compensates for the decreasing out-migration, resulting in a growing population in 2007 (ČSÚ Brno, 2008).

The results of the analysis of the data from the Czech Statistical Office are clear: Brno was a shrinking city between 1996 and 2004 (Fig. 7). However, as soon as other data sources are used, the situation becomes more ambiguous and according to these, a shrinking period of Brno existed, but it was shorter (Fig. 8). The Centre for Regional Development of Masaryk University showed an increase of the number of employed people between 1989 and 1997 and again since 2004 (VCRR MU, 2005). Within the field of demography, the Ministry of the Interior identified a higher number of inhabitants since 2004. Furthermore, the population grew to nearly 400,000 between January 2004 and January 2008 (MV ČR, 2008). Hence, a restricted shrinking period was visible between 1997 and 2003.

No matter whether one looks at seven or nine years of shrinkage, it was certainly a limited period and it is assumed that, in contrast to some eastern German cities, no downward spiral was able to take effect. Furthermore, the proportion of urban shrinkage was less dramatic. The population loss of Brno with about 6 % between 1993 and 2006 was much smaller than for example in Hoyerswerda (– 40 %) or Chemnitz (– 22 %) between 1990 and 2006 (SLS, 2008, author's calculation). The same applies to the labour market. The highest unemployment rate of Brno was much lower than the present one in eastern German shrinking cities (an extreme example is Hoyerswerda with about 26 %).

Nevertheless shrinking as a problem should be discussed in a broader way in the Czech Republic, even if the processes are not as dramatic as in some eastern German cities. The concept of urban shrinkage or shrinking cities could be used in the Czech frame. In the face of the demographic circumstances (TFR << 2.1; ageing) one should assume a mid-term decrease in the population. If the total fertility rate, such as the number of children per women, is lower than 2.1, then this is below the level at which the population can be sustained. In-migration, as a more variable demographic process than the natural population development, could be a way of stabilising the number of inhabitants, but this is a disputable remedy in light of the generally decreasing populations in Europe (EC, 2006). Most cities in the Czech Republic including Brno should adjust to the fact that there will not always be growth. They need to develop strategies to deal with shrinking processes on the city level, at least in the field of population development.

The developments mentioned become more diverse in space and time when we shift the scale to the level of the city districts. On the one hand, there are districts, which record a loss of population within the focus period 1991–2001 (data only available for census years). On the other hand, there are districts, which grew. Mainly inner city districts register losses – first and foremost Brno-Střed, but by contrast, some periphery districts are growing. These benefit from suburbanisation because they are still within the administrative border of Brno. Additionally, a shift of industrial or trade companies is visible from the inner city to the periphery or areas, which are conveniently placed, regarding transport facilities. Inner city shrinking is faced by growth at the urban periphery (Mulíček, 2004). In addition to the spatial and temporal aspects of shrinkage, diverse developments are visible within different fields. Growth in the tertiary sector contrasts with a long-term decline in the secondary sector (VCRR MU, 2005).

A similar difference of growth and shrinkage exists between Brno (administrative unit) and its surrounding municipalities. The suburbanisation in the functional urban region of Brno goes to the expense of Brno municipality. While Brno registered financial and economic losses between 1997 and 2003, Modřice as an example in the south of Brno profits with growth in employment and population.

The set of indicator that this study used gives a good overview of the development of the administrative city in the following three fields: demography, economy and finance. Unfortunately, no data exist on the purchasing power at the city level. This could have given an insight into the development of available money or capital for consumption or investment from the side of the population or small investors. Additionally an availability of data at the level of city districts or for the surrounding suburban municipalities for each year would have led to greater insights on oppositional developments within the city.

## 8. Conclusion

Moderate and temporary decline and losses as well as the linked modest consequences are probably the most striking reasons for the limited debate on urban

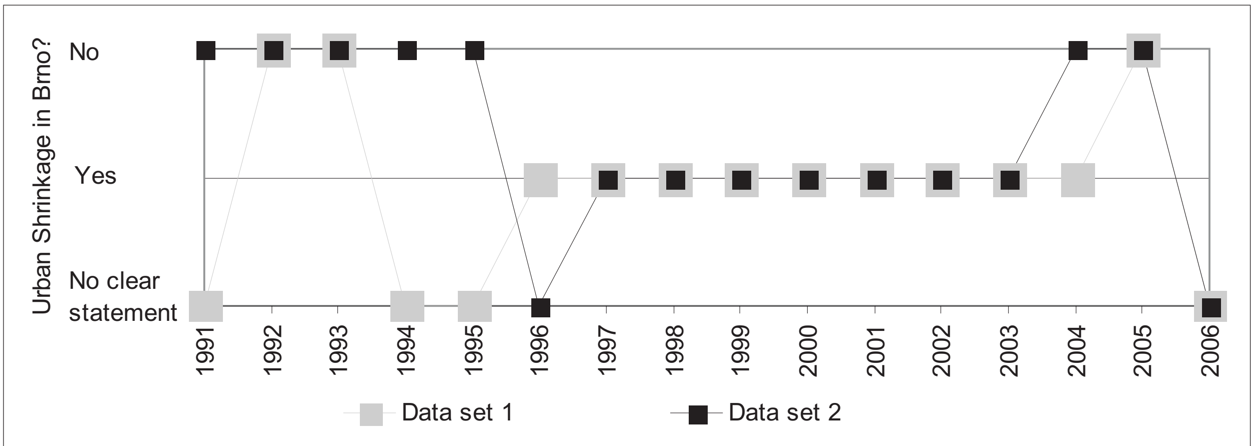


*Fig. 8: Brno and the period of shrinking – comparison of different data sets*
*(source: author's calculation, Data ČSÚ, 2007a,b; MV ČR, 2008; VCRR MU, 2005)*
*Data sets differ in the number of employees, and from 2004 in population development*

shrinkage in the Czech media and between policy makers. In this sense urban shrinkage, as shown by the case study, and the theoretical concept with its limitations should be discussed more broadly and adopted in the Czech framework. The case study reveals that Brno experienced a period of shrinking between 1997 and 2003, and that the causes were a decrease in the population, the economic recession as well as less financial resources. The consequences were not as dramatic as in other, in particular East German shrinking cities. A positive effect was a slightly reduced demand surplus on the housing market, caused by a declining population as well as renovation work and new buildings. A massive number of vacant flats, which is often used as an indicator for shrinking cities in Germany, cannot be found in Brno. This is caused, on the one hand, by a demand for dwellings (depending on the segment) and on the other hand by a relatively strong bonded housing market. The result is an "artificial lack of flats" (Lux, 2000). On another scale, shrinking and growing districts are formed within the administrative border of Brno. In the shrinking districts, the density of use through different functions (e.g. housing, industry) decreases, whereas in the growing ones it increases. One indicator is the number of unused brown fields in former industrial or commercial zones. In the face of demographic developments, a big boom of new housing developments should not be followed, in spite of the recent housing situation. The administrative body of Brno should be involved and should control the situation in order to protect itself against subsequently negative consequences by means of continuous long-term monitoring and urban planning.

## Acknowledgement

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# TRANSPORT HIERARCHY OF CZECH SETTLEMENT CENTRES AND ITS CHANGES IN THE TRANFORMATION PERIOD: GEOGRAPHICAL ANALYSIS

Stanislav KRAFT, Michal VANČURA

**Abstract**

*The presented paper deals with a geographical analysis of main changes in the transport system of Czechia during the transition period by monitoring changes in the transport hierarchy of main settlement centres. Within the research, our attention is focused on long-term tendencies in the development of transport hierarchy, on main changes in transport hierarchy between 1990 and 2005, and on the relation between transport and complex hierarchy of settlement centres.*

**Shrnutí**

***Dopravní hierarchie středisek osídlení Česka a její změny v transformačním období: geografická analýza***

*Předkládaný příspěvek se zabývá geografickou analýzou hlavních změn v dopravním systému Česka v průběhu transformačního období pomocí sledování změn v dopravní hierarchii středisek osídlení. V rámci tohoto sledování se pozornost zaměřuje na dlouhodobé tendence ve vývoji dopravní hierarchie sledovaných středisek, hlavní změny v dopravní hierarchii středisek osídlení mezi roky 1990 a 2005 a vzájemnému vztahu mezi dopravní a komplexní hierarchií středisek.*

***Keywords:*** *transport hierarchy, car transport, transition period, transport geography, settlement centres, Czechia*

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## 1. Introduction

Transport is one of the most important national and world economy sectors and at the same time, it is one of the most significant symbols of modernity. The current society in advanced countries may be characterised as highly mobile and from this point of view dependent on transport. As well as other social-geographic systems, the transport system of the Czech Republic is passing through fundamental quantitative and qualitative changes in its spatial organisation, which are related to the post-socialistic transition. These changes are closely interconnected, whereas the actual transport system changes are in a way connected with simultaneous changes in the settlement patterns of the Czech Republic. The most distinctive changes in settlement pattern organisation can be generally characterised by the concentration and deconcentration of population, available jobs and services e.g. Carter, 1995; Giuliano, 1998; Hanson, 2004; Nuhn, Hesse, 2006; Hampl, 2005). It can be expected that simultaneous changes in the geographical organisation of society during the transition period are related to changes in the geographical organisation of the surveyed transport systems on all geographical scales, from local to macro-regional scales.

However, relevant data are missing and main changes in the geographical organisation of the Czech transport system can be therefore studied only implicitly and with certain generalisation. The study focuses on macro-regional changes within the spatial organisation of the Czech transport system. The main objective of this paper is a geographical analysis of changes in the transport hierarchy of Czech centres during the transition period. The purpose of this work is to find suitable indicators, which can characterize these changes and help in their suitable geographical interpretation. The study is focused mainly on the development of the transport system in the Czech Republic in the transition period after the year 1989, which is closely connected with the substantial dynamics of changes in the spatial organisation of society. Concerning the data availability, the study is focused on changes and effects induced by the growing mobility of people, and on changes in the passenger transport system.

The study is focused on the following basic research topics. Firstly, on long-term trends in the development of transport hierarchy, which represent fundamental frameworks for the research. Then, changes of transport hierarchy during the transition period are studied. Finally, the above-mentioned relation between the transport and settlement hierarchies is studied. Some of these issues were studied by Czech transport geographers (e.g. Hůrský, 1978; Řehák, 1994; Marada, 2003; Marada, 2008), but no study dealt with their development, namely during the period of the post-socialistic transition.

## 2. Transport and spatial organisation

Transport is one of the most important human activities. From a geographical perspective, transport plays a very considerable role both in the society and in the system of national economy, and this is why it is a subject of universal study and interest (Hoyle, Knowles, 1998). Some paradoxes can be seen in transport studies. Transport is mostly referred to as a sector with a relatively great environmental impact on the landscape. At the same time, by its capability to carry goods, people and information it facilitates functioning and sustainable development of settlement and economic structures throughout the world (e.g. Nuhn, Hesse, 2006; Bertolini, 1999). Transport is also a multidimensional activity whose importance is in its historical, social, political, environmental and economic perspectives (Rodrigue et al., 2006). There are two main core concepts in transport geography – accessibility and mobility (Hanson, 2004). Accessibility is in this perspective accepted as a number of opportunities (jobs, shops, transport terminals etc.) available within a certain distance or travel time. The level of accessibility at the same time reflects the existing relations and functional connections of cities, regions and whole countries. Mobility is thus defined as an ability to move between different activity sites (e.g. between home and work place). In the context of actual changes in settlement systems, especially in the context of growing distances between these localities, accessibility is increasingly depending on mobility.

Transport and transport infrastructure also play an important role in regional development and in the integration of regions into integrated economic complexes. Although direct relations between the qualitative transport infrastructure of a certain region and its development is hard to demonstrate, a height-quality transport infrastructure is one of key factors in the regional development (see e.g. Hoyle, Smith, 1998; Bruinsma, Rietveld, 1997; Gutiérrez, 2001; Viturka et al., 2003; Vančura, 2007). H. Nuhn and M. Hesse (2006) studied the significance of transport for the contemporary society and new types of mobility. They claim that the main role of transport is to overcome distances and physical barriers and in fact, that transport creates new spatial potentials. The growing number of spatial interactions among geographical localities and the increasing speed of mobility come along with globalisation. Recent changes in the global transport system can be considered a demonstration of economic globalisation and a demonstration of global transport relations (see discussion e.g. in: Graham, 1995; Janelle, Beuthe, 1997; Keeling, 2007; Sýkora, 2000).

As mentioned above, transport is responsible for the structuring and organisation of geographical space (Seidenglanz, 2007). This thesis is also related to some basic theories and models traditionally used in transport geography. The oldest of them is the Vance model. It is a five-stage mercantile model describing the development patterns in transport networks and related urban hierarchy on the example of trade development between Europe and North America. It points out i.e. the differences between the lengthy development of the urban hierarchy of European cities and the faster hierarchical development of American cities, which are influenced more by the transport networks order. The Rimmer model is an alternative to the previous model, which generalises the process of the rise and development of transport networks in Southeast Asia. In the 1960s, a new sophisticated model called the Taaffe model (Fig. 1) was created by three American authors.

The first phase of Taaffe's model (Scattered ports) is connected with the pre-modern transport networks period. There are a few dispersed seaports with limited hinterlands on the coast, whose importance is approximately equal. The transition to the second phase (Penetration lines and port concentration) is usually evoked by the discovery of new inland raw materials. In an effort to mine these raw materials, access roads are built from selected seaports to new inland localities. The result is a one-way connection from raw material localities to export seaports, emergence of inland distribution centres and growing importance of initially scattered ports connected with inland areas. The third phase (Development of feeders) is characterised by the progressive deepening of settlement hierarchy influenced above all by the spatial layout of transport networks. Other local centres come to existence along the access lines, which fulfil a role of clue-points by connecting seaports and inland centres. The continued growing importance of export-oriented seaports and inland centres is also evident. The growing importance of inland centres is a pre-requisite for transition to the fourth phase (Beginnings of interconnection), when the direct reciprocal connection among the originally isolated inland centres is created. Profitable transport location on all existing connections is the basic development factor for the development of new centre. The high level of transport network connectivity is typical for the fifth period (Complete interconnection). The result of this maximum connectivity is the completion of the settlement hierarchy, whereas the most important centres are reciprocally very well interconnected. In this phase, the expiration of other scattered ports is evident, which were not connected on the incipient transport system and their role is fully assumed by export-oriented seaports. The last phase of Taaffe's model (High priority main streets) is known not only for a high level of connectivity but above all for the existence of hierarchically more important priority connections among the most important centres of the whole transport system. On the other hand, some reductions of poorly used transport links can also be seen. The result of the development is then a comprehensive, high-quality and intensive connection of the most important centres in the whole region. Taaffe's model was modified many times. Its modification to European conditions was made e.g. by J. Brinke, who defines four stages of transport networks development: stage of localized connection, stage of integration, stage of intensification and stage of selection (Seidenglanz, 2008).

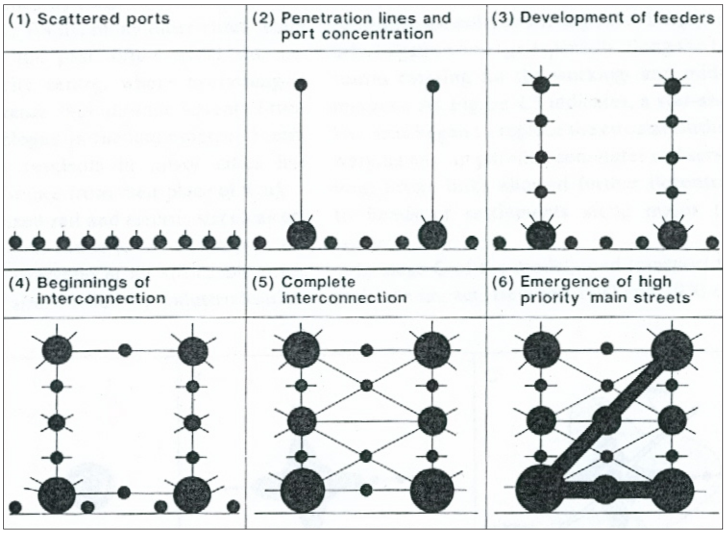


*Fig. 1: The Taaffe model*
*(source: Taaffe, Morrill, Gould, 1963)*

All the above-mentioned models are only generalised patterns of real transport network and transport link developments and their relations with settlement systems. The fact, that all these theories were created on the basis of observation in countries with different levels of transport and settlement systems demonstrates that the use of these models in a contemporary transport system is limited. The significance of these models consists above all in demonstrating the historical relations between transport development and settlement systems.

## 3. Research method

There are two main methodological problems when studying transport hierarchy and its relation to settlement hierarchy. The first one is the representative selection of surveyed centres. There are a few approaches for how to define centres in geographical transport studies. The most common approach is by using the quantitative transport characteristics of particular centres (e.g. Viturka, 1975; Hůrský, 1978; Řehák, 1979; Kozanecka, 1980). These authors argue that only the satisfactory level of transport features (e.g. number of public transport links or road traffic intensity) of surveyed centres is a suitable indicator of transport centres.

The main problem resulting from this approach is, however, the fact, that some centres have a good transport location and subsequently a high level of transport features, but its complex importance is sometimes lower. Conversely, some centres can be situated in a worse transport location and have unsatisfactory transport characteristics but their complex importance is probably higher. Hence, some authors consider comprehensive characteristics as more suitable indicators for the definition of centres in transport geographical studies (e.g. Marada, 2003, 2008). Centres surveyed in this study are taken over from Hampl's socio-geographical regionalisation of the Czech Republic from 2001. Hampl (2005) specified 144 centres of at least micro-regional importance according to their complex size index. The complex size index is an aggregate indicator based on the residential and labour functions of these centres.

The second methodological problem results from the above mentioned data availability and data responsibility. The study is focused on the dynamics of passenger transport systems in the Czech Republic in the transformation period and its relation to the settlement system organisation. Unfortunately, there are no deeper and detailed surveys of personal travelling in the Czech Republic (see e.g. National Travel Survey in Great Britain). This is why the transport geographers usually make use of public transport connections (Hůrský, 1978; Řehák, 1979; Marada, 2003; Seidenglanz, 2007) or – less often – of road traffic intensity (Viturka, 1975). Regarding the most important transport mode in the Czech Republic, we use data from the road transport census conducted every five years by the Road and Motorway Directorate of the Czech Republic (ŘSD). These data are the sums of all transport volumes (trucks, private cars, motorcycles) measured at census points situated on a greater part of Czech roads (in this study transport size = average amount of vehicles entering or departing the centre per 24 hour period). Unfortunately, the greatest weakness of this transport census is namely the fact, that there is no direct possibility for how to differentiate what part of total transport volume falls to transit transport and what part falls to "real" local transport between the centre and its hinterland.

Changes in the surveyed centres' transport hierarchy during the transition period and their relationship to the settlement patterns of the Czech Republic are then valuated by using traditional basic characteristics of settlement geography, namely by the rule of size order (size hierarchization of centres), which can serve as a comparative model for distinguishing the level of hierarchization (Marada, 2008). Detailed relations between transport and settlement hierarchy are then evaluated by the Pearson product-moment correlation coefficient, which demonstrates the association of both monitored types of hierarchization. Concentration of transport intensity in the centres is finally expressed by the Lorenz concentration curve.

## 4. Results

### *4.1 Long-term trends in the development of transport hierarchy*

The analysis of the road transport census in the surveyed centres provides a few basic features of the development of transport hierarchy from a longer time perspective. This research is important for checking the long-term tendencies in transport hierarchy and at the same time for the basic comparison with general simultaneous tendencies in settlement patterns. The analysis included road transport censuses from 1990, 1995, 2000 and 2005. Using data from Viturka's study (1975), it was possible to characterize main tendencies of transport hierarchy in centres before 1990, too (Transport Census in 1973). Long-term trends in the development of transport hierarchy of the surveyed centres are shown in Tab. 1.

As to the size hierarchy of complex and transport characteristics of the surveyed centres, we can see some relevant long-term tendencies in the spatial settlement and transport patterns of the Czech Republic. The most important finding is a continually intensifying hierarchization of centres in both monitored types of studied hierarchies. In the case of complex size, the system of centres naturally shows a much more developed hierarchy than in the case of transport size. The reason is likely the fact that transport flows are much more equably distributed within the space than population or available jobs. The comparison of complex and transport hierarchies further points to other differences of the two indicators. The hierarchization of the complex sizes of centres in both years shows that only the last size category ($35^{th}$–$98^{th}$ centre) is equivalent to the size of the first centre (Prague). Other size categories have a less developed hierarchy, which results from a longer historical development of settlement patterns in the Czech Republic (Hampl, 2005). Conversely, the size hierarchization of transport features exhibits different tendencies. Each size category of transport hierarchy surmounts the transport significance of the first centre. Nevertheless, even in these tendencies we can see a certain development of the transport hierarchy during the period of transformation. Evident is the growing importance of the first centre (Prague). A relevant indicator for this assessment is the rate of hierarchization (see notes under Tab. 1). This indicator refers to the growing importance of the biggest centres in the transport hierarchy of the Czech Republic (18.6 for year 1973 and 26.9 for year 2005), which results from the distinctive concentration of transport flows and transport infrastructure in the biggest settlement centres. The transport hierarchy development before and after the year 1989 facilitates

| Rank | Relativizated sizes (The 1st centre = 100) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Complex size | | Transport size | | | | |
| | 1991 | 2001 | 1973 | 1990 | 1995 | 2000 | 2005 |
| 1st | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2nd – 4th | 83 | 74 | 120 | 133 | 129 | 124 | 106 |
| 5th – 12th | 50 | 49 | 194 | 209 | 208 | 187 | 171 |
| 13th – 34th | 93 | 85 | 400 | 409 | 385 | 324 | 289 |
| 35th – 98th | 112 | 104 | 783 | 759 | 668 | 553 | 475 |
| **Degree of hierarchization** | 89.3 | 92.1 | 18.6 | 20.0 | 21.8 | 25.5 | 26.9 |

*Tab. 1: Size hierarchization of complex and transport features*
*(source: Viturka 1975, Hampl 2005, Marada 2008, Transport census ŘSD)*
*Notes: 1. Degree of hierarchization = 100 times ((size of the 1st – 4th centre) / (size of the 13th – 98th centre)). The degree of hierarchization indicator demonstrates the size of the largest centres in proportion to the size of medium-size and small centres. Values lower than 100 correspond to a lower degree of hierarchization than presumed by the rank-size rule, values higher than 100 to a higher degree of hierarchization.*
*2. The data relating to transport census from the year 1973 are borrowed from Viturka's study (1975). This study was made by a different methodology. A possibility to compare the data with other outputs is thus only partial.*

a very interesting comparison. The transport hierarchy of the surveyed centres is least developed in 1990. This might have been caused by planned socialist development of settlement centres in the 1970s and 1980s, which suppressed the trends of natural hierarchization in the settlement structure, namely in relation to the development of higher size categories of centres (e.g. Hampl, Gardavský, Kühnl, 1987). This is why the transport hierarchy status in 1990 rather reflects the previous socialist period in the settlement structure.

A different view of this development provides the evaluation of changes occurring in the transport concentration processes. This phenomenon can be appropriately illustrated in this study by using the Lorenz concentration curve, which allows a comparison between these concentrations in both monitored years (Fig. 2). Transport censuses from the years 1990 and 2005 were analysed. The comparison of both curves points to a conspicuously asymmetrical distribution of transport volumes in the surveyed centres. A half of all transport volumes was concentrated in 29 % of centres in 1990 (23% of centres in 2005). Thus, the concentration curve for 2005 is more rounded than that for 1990. It again points to the intensifying transport hierarchization of the surveyed centres and to the growing importance of the biggest centres in the spatial distribution of transport flows.

#### *4.2 Transport hierarchy of Czech settlement centres in 1990*

Transport hierarchy of Czech settlement centres in 1990 constitutes a start-up phase of detailed research and naturally a reflection of socialistic development. All 144 centres were analyzed by using the indicator of relative transport size (= all vehicles entering and leaving the centre; all centres = 10,000). In 1990, the most important transport centres were the largest settlement centres in the Czech Republic (Praha, Brno, Ostrava, and Plzeň). All these are centres whose position within the transport system is conditioned by their population size and significance of their labour market. The main feature of this hierarchy is at the same time the fact there are also centres of relatively lower complex significance occurring between the most important centres such as Uherské Hradiště, Tábor and Mladá Boleslav. Their transport significance stems out from their good location within the road transport network (similarly for public transport e.g. Marada, 2003).

Conversely, the centres of relatively greater complex importance, that are situated in less favourable transport locations (e.g. Tachov, Dvůr Králové nad Labem, Uničov) appear at lower levels of transport hierarchy. Good or bad transport locations are thus a key factor influencing the distinctive asymmetry between the transport and settlement hierarchies of the surveyed centres. Tab. 2 presents twenty largest and smallest centres according to their relative transport size in 1990.

The asymmetry between transport and settlement hierarchies causes substantial differences in ranking the centres by transport and complex sizes. Centres with the most favourable transport location are

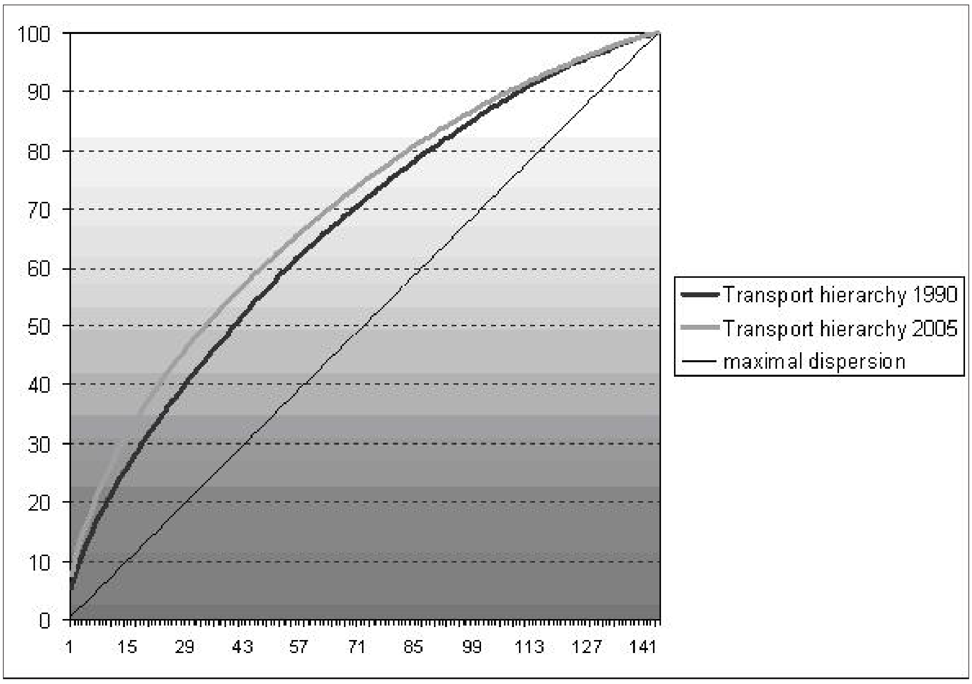


*Fig. 2: Lorenz concentration curve for transport hierarchy 1990–2005 (source: Transport census ŘSD)*

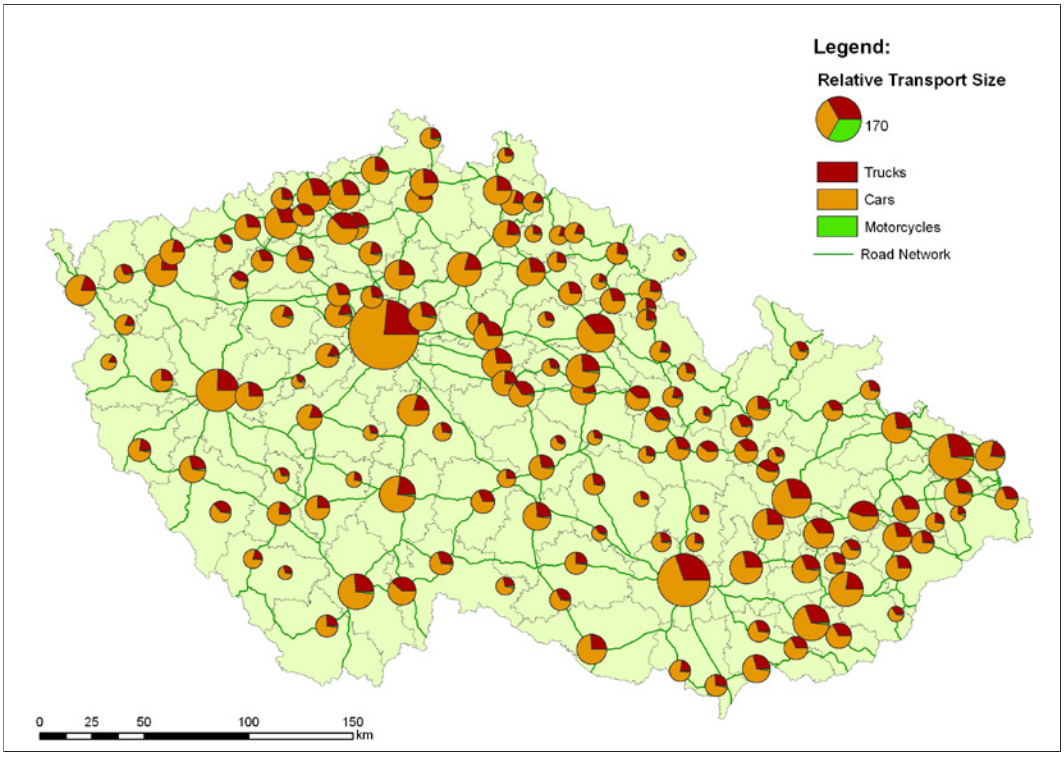


*Fig. 3: Transport hierarchy of Czech settlement centres (1990)*

Třeboň (difference between transport hierarchy and complex hierarchy is 87 points), Lovosice (82 points), Poděbrady (72 points), Nový Bor and Čáslav (55 points). This discrepancy can be caused by other reasons too (e.g. spatial differentiation of road transport intensities in the Czech Republic or public transport quality), but the factor of transport location can be considered the most important of all. By contrast, centres with the most unfavourable transport location are Sokolov (74 points), Blansko (71 points), Kadaň (58 points), Dvůr Králové (55 points) and Litvínov (53 points). All these centres display a substantially lower relative transport size than their complex size is. These centres are situated aside important transit communications and we can suppose that they are relatively least affected by transit or irregular transport.

#### *4.3 Transport hierarchy of Czech settlement centres in year 2005*

The transport hierarchy of Czech settlement centres in 2005 was evaluated analogically, i.e. at the time of the last transport census conducted in the Czech Republic. This year can be considered a final stage of the transformation period. The most important transport centres were again the largest settlement centres of the Czech Republic (Praha, Brno, Ostrava and Plzeň), but their dominance over other centres is notably lower. In this respect, the declining transport size between the four largest centres and the other centres is much more continual. The above-mentioned asymmetry between the transport and settlement hierarchies can be once again documented by the fact, that there are also centres of lower complex significance among the most important transport centres (Prostějov, Mladá Boleslav, Frýdek-Místek and Hranice). These centres are advantaged by their good transport location again; they usually serve as the most important road transport crossings in the Czech Republic. On the other hand, there are the smallest centres according to their relative transport size here too (Chotěboř, Prachatice, and Broumov). The main feature of the two studied hierarchies consists in significant qualitative changes in the relative transport size of all surveyed centres. The relative transport size of the first centre (Praha) was 527.3 in 1990 while in 2005 it was only 757.2. By contrast, the relative transport size of the smallest centre (Broumov)

| Rank | Centre | Relative transport size | Rank | Centre | Relative transport size |
|---|---|---|---|---|---|
| 1. | Praha | 527.3 | 125. | Polička | 31.3 |
| 2. | Brno | 290.7 | 126. | Semily | 30.7 |
| 3. | Ostrava | 218.0 | 127. | Uničov | 29.5 |
| 4. | Plzeň | 191.5 | 128. | Lanškroun | 27.6 |
| 5. | Olomouc | 161.9 | 129. | Nový Bydžov | 27.1 |
| 6. | Hradec Králové | 155.2 | 130. | Milevsko | 27.0 |
| 7. | Uherské Hradiště | 139.6 | 131. | Blatná | 26.6 |
| 8. | Tábor | 139.0 | 132. | Tachov | 26.5 |
| 9. | České Budějovice | 133.8 | 133. | Frýdlant | 26.3 |
| 10. | Zlín | 126.1 | 134. | Dvůr Králové nad Labem | 26.2 |
| 11. | Mladá Boleslav | 124.6 | 135. | Valašské Klobouky | 25.5 |
| 12. | Pardubice | 124.2 | 136. | Velké Meziříčí | 25.5 |
| 13. | Most | 118.8 | 137. | Frýdlant nad Ostravicí | 25.1 |
| 14. | Teplice | 115.5 | 138. | Sedlčany | 25.0 |
| 15. | Vyškov | 111.8 | 139. | Bystřice nad Pernštejnem | 24.3 |
| 16. | Karlovy Vary | 110.3 | 140. | Hlinsko | 23.6 |
| 17. | Lovosice | 106.3 | 141. | Chotěboř | 23.1 |
| 18. | Benešov | 105.0 | 142. | Hořovice | 21.1 |
| 19. | Prostějov | 103.8 | 143. | Prachatice | 20.0 |
| 20. | Opava | 98.6 | 144. | Broumov | 16.8 |

*Tab. 2: The largest and smallest centres according to their relative transport size (1990) (source: Transport census 1990, ŘSD)*
*Note: Relative Transport Size = all transport volumes entering or departing the centre; all centres = 10,000*

was 16.8 in 1990 but only 13.0 in 2005. Thus, the studied system of settlement centres shows a growing variation interval between the maximum and minimum relative transport size. Among other things, this points to the growing significance of the first centre. Twenty largest and smallest settlement centres according to their relative transport sizes in 2005 are presented in Tab. 3.

Similarly as in the previous evaluation, the above documented differences in the order of centres according to their complex and transport size is evident. Centres that are advantaged by good transport locations are namely Lovosice (by 69 points), Mohelnice (by 65 points), Litomyšl (by 60 points), Čáslav (by 59 points) and Hranice (by 53 points). The most distinctly growing dynamics can be seen in centres situated on the R35 or I/35 road (Olomouc, Mohelnice, Litomyšl, Vysoké Mýto, Hradec Králové), which is an alternative communication to the most exploited expressway D1. Conversely, the most disadvantaged centres due to their transport location are Sokolov (by 63 points), Litvínov (by 59 points), Dvůr Králové (by 54 points), Příbram (by 51 points) and Kadaň (by 50 points). Although the disproportions are considerable, a certain convergence between the two types of hierarchy during the transformation period is evident.

### *4.4 Correlations between the transport and settlement hierarchies*

The correlation between the transport and settlement hierarchies can be documented also by using basic statistical methods. The goal of this evaluation is to demonstrate the mutual dependence of the two studied hierarchies and the development of this correlation during the transformation period. The assessment includes both all components of the complex hierarchy

| Rank | Centre | Relative transport size | Rank | Centre | Relative transport size |
|---|---|---|---|---|---|
| 1. | Praha | 757.2 | 125. | Sušice | 28.9 |
| 2. | Brno | 377.9 | 126. | Dačice | 28.8 |
| 3. | Ostrava | 230.1 | 127. | Uničov | 28.7 |
| 4. | Plzeň | 191.2 | 128. | Nový Bydžov | 27.4 |
| 5. | Olomouc | 190.6 | 129. | Vlašim | 27.4 |
| 6. | Hradec Králové | 185.8 | 130. | Lanškroun | 27.2 |
| 7. | Prostějov | 183.2 | 131. | Hořovice | 26.5 |
| 8. | Mladá Boleslav | 159.5 | 132. | Vimperk | 26.3 |
| 9. | Frýdek-Místek | 155.6 | 133. | Sedlčany | 25.7 |
| 10. | Pardubice | 148.3 | 134. | Dvůr Králové nad Labem | 25.4 |
| 11. | České Budějovice | 142.8 | 135. | Semily | 23.2 |
| 12. | Hranice | 129.2 | 136. | Blatná | 22.8 |
| 13. | Teplice | 122.8 | 137. | Hlinsko | 22.6 |
| 14. | Uherské Hradiště | 122.4 | 138. | Frýdlant | 22.5 |
| 15. | Ústí nad Labem | 122.1 | 139. | Tachov | 21.4 |
| 16. | Zlín | 120.0 | 140. | Podbořany | 20.5 |
| 17. | Kolín | 115.9 | 141. | Bystřice nad Pernštejnem | 20.2 |
| 18. | Liberec | 112.8 | 142. | Chotěboř | 18.9 |
| 19. | Vyškov | 110.8 | 143. | Prachatice | 17.4 |
| 20. | Tábor | 107.5 | 144. | Broumov | 13.0 |

*Tab. 3: The largest and smallest centres according to their relative transport size (2005)*
*Source: Transport census 2005, ŘSD*
*Note: Relative Transport Size = all transport volumes entering or departing the centre; all centres = 10,000*

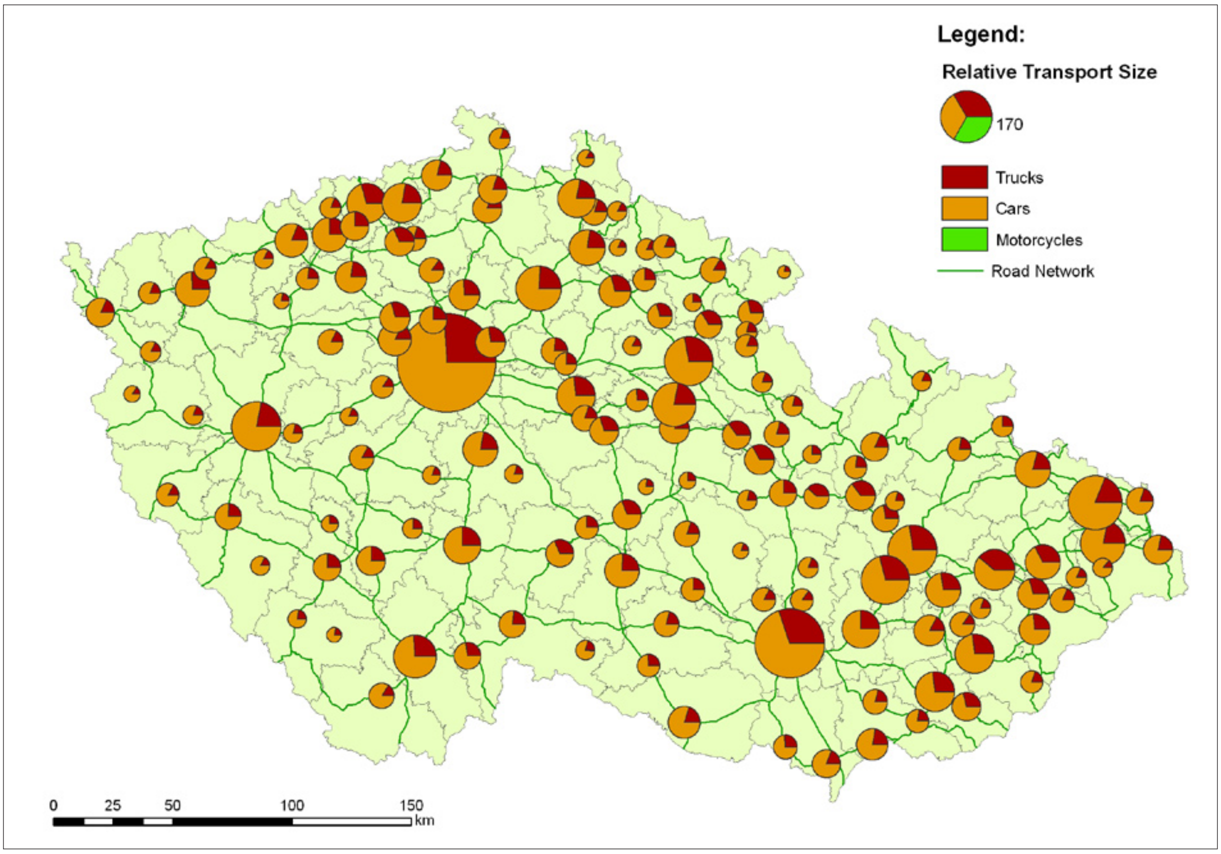


*Fig. 4: Transport hierarchy of Czech settlement centres (2005)*

(complex size, labour size and population size) and components of the transport hierarchy (volumes of trucks, cars and motorcycles). The Pearson product-moment correlation coefficient is used to monitor which component of transport hierarchy is more closely associated with the complex hierarchy and which component of complex hierarchy is most associated with the transport hierarchy.

In terms of previous evaluations, we can suppose the existence of a higher association between complex and transport indicators for the passenger-car transport, which shows the highest spatial dispersion in all studied years. Lower association can be expected in the indicators of truck transport, which is more oriented to long-distance (transit) transport. The absolutely lowest correlation can be expected in motorcycles; this transport mode is not markedly concentrated and represents only a minor share of all transport volumes. In respect of assessing the dynamics of these relations, a higher association among all monitored categories can be expected in 2005 than in 1990.

In terms of monitoring the whole set of settlement centres in 1990 (Tab. 4), a relatively close dependence can be seen among all components of transport and complex hierarchies. A very tight dependence (0.889) is characteristic of relation between the main components of both types of hierarchy ("CS" and "ATV"), which demonstrates a distinctive interconnection between the two monitored systems. The closest dependence on the components of complex hierarchy (CS, LS, PS) is typical for passenger-car transport (analogical values 0.900; 0.902; 0.897). Thus, the individual car transport is the most important component of transport hierarchy in relation to the settlement system organisation. A lower correlation is then seen between the complex characteristics and truck transport, which is a consequence of the above-mentioned orientation to the transit transport of this transport mode. On the other hand, the evaluation demonstrates a close relation among all transport indicators and labour size of settlement centres. This indicator is thus the most significant component of complex hierarchy in relation to transport characteristics.

Table 5 shows an increasing level of association between the components of transport and complex hierarchies. The closer dependence between the main components of both hierarchies (0.930) results especially from the above-mentioned convergence between transport and complex characteristics. Thus, transport indicators correspond with actual changes in the settlement systems more in 2005 than in 1990.

| | CS | LS | PS | TV | CV | MV | ATV |
|---|---|---|---|---|---|---|---|
| **CS** | *1.000* | *0.999* | *0.999* | 0.818 | 0.900 | 0.648 | 0.889 |
| **LS** | *0.999* | *1.000* | *0.999* | 0.821 | 0.902 | 0.649 | 0.892 |
| **PS** | *0.999* | *0.999* | *1.000* | 0.813 | 0.897 | 0.645 | 0.886 |
| **TV** | 0.818 | 0.821 | 0.813 | 1.000 | 0.936 | 0.730 | 0.966 |
| **CV** | 0.900 | 0.902 | 0.897 | 0.936 | 1.000 | 0.758 | 0.996 |
| **MV** | 0.648 | 0.649 | 0.645 | 0.730 | 0.758 | 1.000 | 0.764 |
| **ATV** | 0.889 | 0.892 | 0.886 | 0.966 | 0.996 | 0.764 | 1.000 |

*Tab. 4: Paired correlation among components of complex and transport size hierarchies (1990) (source: Hampl, 2005 ; Transport census 1990; ŘSD)*
*Note: CS – complex size; LS – Labour size; PS – Population size; TV – trucks volume; CV – car volume; MV – motorcycles volume; ATV – all transport volume*

| | CS | LS | PS | TV | CV | MV | ATV |
|---|---|---|---|---|---|---|---|
| **CS** | *1.000* | *0.999* | *0.997* | 0.890 | 0.937 | 0.867 | 0.930 |
| **LS** | *0.999* | *1.000* | *0.994* | 0.893 | 0.937 | 0.897 | 0.931 |
| **PS** | *0.997* | *0.994* | *1.000* | 0.881 | 0.935 | 0.858 | 0.926 |
| **TV** | 0.890 | 0.893 | 0.881 | 1.000 | 0.969 | 0.903 | 0.984 |
| **CV** | 0.937 | 0.937 | 0.935 | 0.969 | 1.000 | 0.927 | 0.998 |
| **MV** | 0.867 | 0.897 | 0.858 | 0.903 | 0.927 | 1.000 | 0.927 |
| **ATV** | 0.930 | 0.931 | 0.926 | 0.984 | 0.998 | 0.927 | 1.000 |

*Tab. 5: Paired correlation among components of complex and transport size hierarchies (2005) (source: Hampl, 2005; Transport census 2005; ŘSD)*

The closest correlation for the components of complex hierarchy (CS, LS, PS) is again typical for passenger-car transport (analogical values 0.937; 0.937; 0.935). The relatively closer dependence is then characteristic for truck road transport (0.890; 0.893; 0.881) and for motorbikes (0.867; 0.897; 0.858). The closest correlation of all studied characteristics is that between transport indicators and labour size of settlement centres (0.893; 0.937; 0.897 and 0.931).

## 5. Conclusion

Results of our analyses showed that the transport system of the Czech Republic went through relatively distinctive changes in its spatial organization during the transformation period. The synthesis of all surveyed issues can be summarized in the following conclusions:

1. In terms of monitoring the long-term tendencies in development of the transport hierarchy of settlement centres, a deepening of hierarchization tendencies occurred in the transformation period and a certain convergence between the development of the given hierarchy and general trends in the geographical organization of the society. The most conspicuous change is the increasing transport significance of the largest settlement centre (Praha), which is typical especially for the transport hierarchy of year 2005.
2. The transport hierarchy of Czech settlement centres experienced considerable quantitative and qualitative changes between 1990 and 2005. The most substantial changes can be characterized by the growing variation interval between the maximum and the minimum value of relative transport significance, which indicates the increasing transport significance of the largest transport/settlement centres and the decreasing transport significance of the smallest centres. The convergence of transport hierarchy to general trends in settlement patterns results at the same time in the decreasing asymmetry between the transport and settlement hierarchies.
3. As to the monitoring of correlation between the transport and settlement hierarchies, a relatively close link was demonstrated between all components of the settlement and transport hierarchies. The development of this correlation was closer

in 2005 than in 1990. The closest links between the settlement and transport hierarchies were shown to exist in the volume of car transport and in the labour size of centres, which demonstrates a close relation between the two components.

In conclusion, we point out that the character of used data is problematic because the data illustrate the studied issue only implicitly and with a certain generalization. Previous analyses elucidated some aspects of relations between the transport and geographical organisation of the society. Therefore, the authors will focus their follow-up research on other geographical scales (meso- and microregional), which however call for different research methods.

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*Fig. 5: Damaged spruce-bilberry forests with clearings near Tatranská Lesná (June 2008) (Photo V. Falťan)*

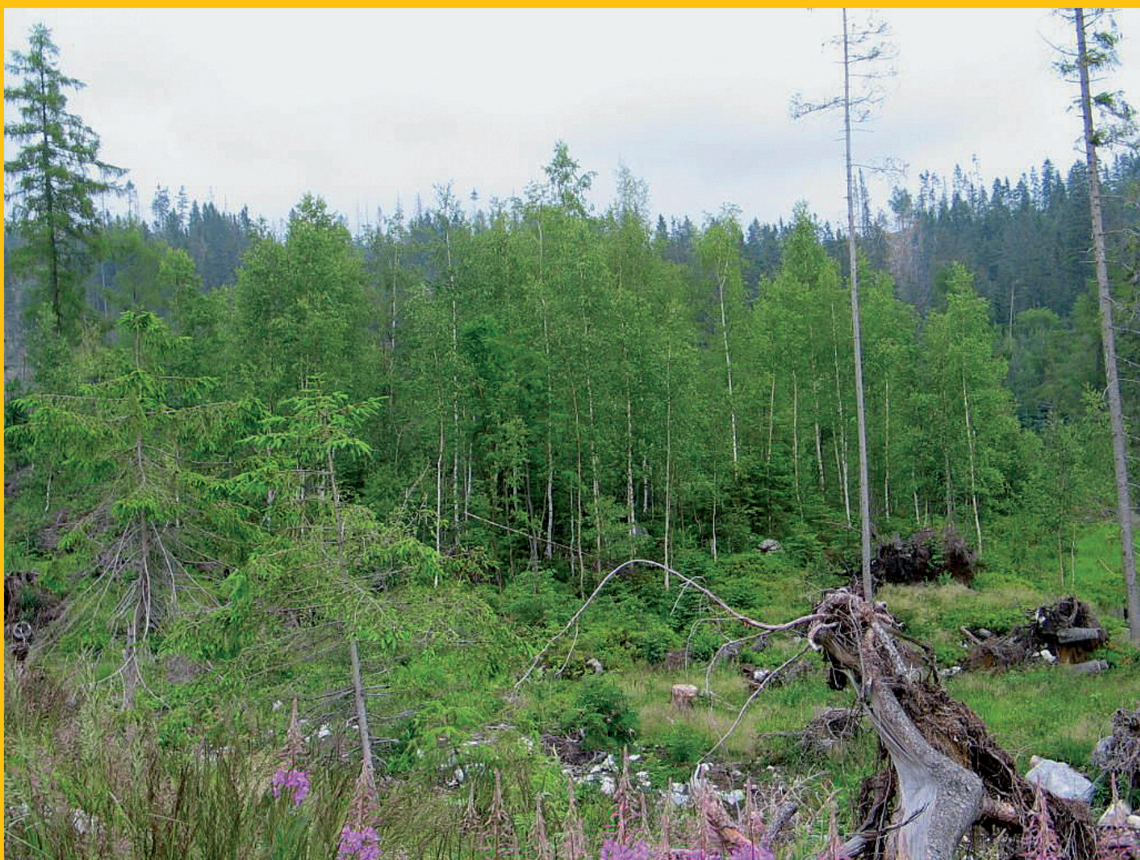

*Fig. 6: Mixed pioneer forests near Tatranské Zruby (June 2008) (Photo V. Falťan)*

Illustrations related to the paper by V. Falťan et al.