ISSN 1822-427X print
ISSN 1822-4288 online

THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

http://www.bjrbe.vgtu.lt

2006, Vol I, No 4, 157–166

ANALYSIS OF LITHUANIAN GRAVEL ROADS PAVING PROGRAMME IMPLEMENTATION IN 1998–2005

Skirmantas Skrinskas[1], Arvydas Domatas[2]

[1]Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
E-mail: mokslas@zvyras.lt
[2]Transport and Road Research Institute, I. Kanto g. 25, mail box 2082, LT-44009 Kaunas, Lithuania
E-mail: a.domatas@tkti.lt

Abstract. The article presents the research based on economic feasibility evaluation of model KAMIS developed for paving* of gravel roads. The model is built for Lithuanian climatic, economic and technological conditions, but it could be adopted in other regions, especially regions with "freezing and thawing climates". After 8 years of model application for appraisal of Lithuanian Gravel Roads Paving Programme it was estimated that consequences after the presented Lithuanian Gravel Roads Conditions Research and KAMIS model application have accumulated 1,09 billion LTL (316 million €) gain for Lithuanian society. Conclusions and findings of the Analysis of Lithuanian Gravel Roads Paving Programme implementation from 1998 to 2005 are presented at the end of the article.

Keywords: gravel roads, asphalt paving, investment appraisal, economic valuation model, roughness, KAMIS, HDM-IV.

1. Introduction

Lithuanian Gravel Roads Paving Programme was started in 1998 and is still continued. This article describes the extensive scientific basis of the Programme why it enabled the society of Lithuania to a Net Present Value (NPV) gain of 1,09 billion LTL (316 million €) by investing 758 million LTL (220 million €) and paving 1632 km of state gravel roads within 8 years and decreasing the share of gravel roads in the state road network from 49,2 % to 40,1 % with an average Internal Rate of Return (IRR) of 23 %.

The Programme was based on the extensive Research of Conditions of Lithuanian Gravel Roads and later building of a Gravel Road Paving Economic Feasibility Evaluation Mathematical Model KAMIS (**K**elių **A**sfaltavimo **M**odel**IS**) designed for Lithuanian climatic, geomorphologic and engineering conditions. The model was presented and defended in 1998 in Skirmantas Skrinskas Doctoral thesis "Research of the Condition of Lithuanian Gravel Roads and Feasibility of their Renovation" in Vilnius Gediminas Technical University [1].

In the same year, based on economic calculations enabled by KAMIS model, the first international funding was given to the Lithuanian Gravel Roads Paving Programme initiated by Lithuanian Road Administration and the World Bank. Transport and Road Research Institute scientists participation in an initial research and continuous application of KAMIS model as well as strong cooperation in the analysis of the Programme implementation in 1998–2005 and up to 2008 seriously strengthens the presented research findings.

The range of condition of state gravel roads was and still is extremely wide. Pavement width varies from 4 to 12 m, gravel pavement thickness from 0 to 80 cm, the average yearly road roughness from 5 to 14 m/km IRI. These roads are situated in a wide range of geomorphologic and hydro-geologic conditions and are affected by different vehicle flows ranging from 40 to more than 1000 vehicle per day (vpd) of an Average Annual Daily Traffic (AADT).

Before the start of the described research Lithuanian economy was shifting from the planned to market economy and resulted in the decrease of the country's economic capacity and ten-fold cuttings of budgetary allocations for the

* Paving within the article is assumed and applied as paving of former gravel paved road with a new asphaltic or asphalt concrete pavement.

gravel road repairs and maintenance. Investments into gravel roads were as well lagging, because of the lack of research on gravel roads data and because of the absence of locally applicable economic evaluation models. The importance and need of the system for management of maintenance and paving of gravel roads based on market economy criteria were obvious [2].

2. Initial research and KAMIS model

The research objective was a scientific substantiation of common threshold values for paving gravel roads. The substantiation was done by building a mathematical model for evaluating the economic feasibility of paving gravel roads under current Lithuanian economic and climatic conditions.

In gaining the research objective, the following tasks were solved:

- the world's most famous gravel road condition evaluation and paving economic appraisal systems and models were analysed,
- according to a specially designed methodology, a detailed research and analysis of condition of gravel roads in Lithuania were performed (gravel pavement roughness was proven to be the most important road condition criterion),
- the most common and reliable under local climatic conditions asphalt pavement structures were analysed and compared with similar foreign practices,
- locally applicable gravel road paving economic feasibility evaluation mathematical model KAMIS was built for joint economic analysis of road paving and paved road maintenance expenses, gravel road maintenance, road users and environmental cost savings,
- the model was tested and introduced to the bodies of Lithuanian Road Administration [2].

2.1. Initial research scope, methodologies and findings

Theoretic, experimental, road engineering and economic research planning and implementation stages were related to different scopes and were structured on different methodological grounds. Major research fields are shortly presented separately.

2.1.1. Theoretic research

The TRRL (UK) research in Africa, GEIPOT and World Bank studies in Brazil and the data from South African SURF model were compared on the basis of pavement roughness related matters.

In total more than 100 publications in English, Russian, Lithuanian, Finnish and Faeroes on the subjects of gravel roads and their renovation were analysed or reviewed.

2.1.2. Experimental research

Research methodology covered the principles of the selection of gravel road test regions and sections. It was foreseen that experimental research results should be of an adequate accuracy to solve the research tasks. It was also planned that the research should cover the best and the worst road maintenance conditions, different (but prevailing in the country) geo-morphologic areas, different (but prevailing) quality and genesis of local gravel material, but should be executed in the major climatic regions with an average rainfall, and should represent the country's data averages. The country's third best (Ukmergė) and the second worst (Kaišiadorys) maintenance districts met the all stated requirements. In each of the districts five 3,0–3,3 km length test sections in the best, the worst, one with the most intensive traffic, average reconstructed and average unreconstructed gravel road sections were selected. Five additional 2,55–5,0 km gravel road sections in Kaišiadorys, Ukmergė and Kelmė districts were included for the calibration of a roughness measuring device, former regular traffic counting places and measurements of roughness increase after blading.

The length of the test sections – approx 3 km – more than 10 times exceeds the practice from other similar (of primary roughness) surveys, but gave less bias and more accurate results.

Experimental research included traffic surveys, gravel road condition research, and road roughness measurements.

Traffic surveys were executed in order to identify the actual traffic volumes on Lithuanian gravel roads and to measure the traffic flow composition in order to use the research data for estimating the vehicle operating costs (VOC). Surveys were organised in 1994–1995 and comprised two stages: traffic counts on the test sections and traffic surveys on the pre-selected as with the most intensive traffic gravel roads in the 39 of 44 Lithuanian districts. Traffic surveys on 15 test sections were done according to the recommendations of Finnish National Road Administration (128 h/year). Traffic surveys on other 225 gravel road sections (88 of them led through settlements) were organised according to the methodology developed by "Transport and Road Research Institute" (6 h/year). Both traffic surveys totalled 555 counts and lasted 3149 hours (or 151 day and 5 hours).

Research results showed that AADT on gravel roads in 1994–1995 ranged from 40 to 1080 vpd. The highest traffic on gravel roads in settlements reached 850 vpd. AADT in Kaišiadorys district gravel roads was 261 vpd, in Ukmergė district 158 vpd.

Gravel road condition research was aimed at an investigation of an actual condition of state gravel roads and to compare findings with the requirements of design standards and regulations. Gravel road technical condition directly affects expenses required for road paving. Condition research consisted of road width and gravel pavement thickness measurements, pavement gravel mixture composition (including percentage of clay, dust and silt) research, embankment and drainage system inspection and measurements of the stopping sight distance. Total of 129 sets of technical condition evaluation tests were executed on the chosen gravel road sections.

Condition's research results showed that 60 % of gravel roads met the technical requirements of design standards. These results also proved that in 19,7 % of the length of gravel roads additional works for extending the sight distance in case of paving would be required. It was estimated that 48,2 % of Lithuanian gravel roads could be paved without their reconstruction, and required changes in a base course mixture composition could be made with a help of a specially designed aggregate mixture composition of a levelling course.

Road roughness measurements had 4 major tasks: 1) to get exact figures on longitudinal pavement roughness according to the International Roughness Index (IRI) scale; 2) to analyse, if roughness reflects other gravel road condition parameters; 3) to estimate the curve of roughness progression after blading in order to make recommendations for simplified roughness measurements; 4) to get accurate data for further economic analysis.

The first task comprised two stages – roughness measurements on the selected gravel road sections using Russian made towed bump integrator PKRS-2u and research on the relationship between the PKRS-2u and IRI measurement scales. The first stage totalled 312 roughness measurements (both directions each time) before and after blading, on which 922,2 km of gravel roads were metered from March to October, 1994. During the second stage, in 1995, 420 roughness measurements (252 of which on gravel roads) were done on 126 km of gravel (75,6 km) and paved roads. TRRL designed MERLIN device was used as a reference to IRI scale [2].

Research on the relationship between the PKRS-2u and IRI measurement scales resulted in few equations. Relationship between PKRS-2u and IRI scales for gravel roads; relationship between PKRS-2u and IRI scales for asphalt roads as well as a curve of roughness progression after blading were estimated based on roughness research [1, 3].

Final roughness and other main results of gravel road condition research are presented in Table 1 [1, 2, 4].

Results presented in the Table proved that roughness reflects other gravel road condition parameters and could be used as a major gravel and paved road condition evaluation criteria. Based on roughness valuation according to the World Bank requirements, it was estimated that 42 % of state gravel roads were in good condition, 40 % satisfactory and 18 % poor. In comparison with other world regions, gravel roads conditions in Lithuania in general were better.

Results, presented in the experimental research, led to the conclusion that the situation of a wide range of gravel road condition required developing of a simple gravel road management system. AADT values increase justified the importance of creation of a model for evaluating an economic feasibility of paving of gravel roads.

2.1.3. Road engineering research

Before building a final economic evaluation model, several basic engineering decisions were made. The decisions were associated with the selection asphalt pavement structures, gravel and paved road maintenance policies and with their economic valuation. Based on the inventory of

Table 1. Results of the major parameters of Lithuanian gravel roads condition research

Studied parameters and test districts	AADT, vpd	Pavement width, m	Pavement thickness, cm	Matching the standard mixture composition, %	Clay, dust and silt, %	Roughness m/km IRI
Kaišiadorys district[1]						
Mean	261	9,4	29	70	7,6	9,9
Maximum	750	12,2	47	90	9,8	12,5
Minimum	90	7,4	141	40	4,9	7,2
Ukmergė district						
Mean	158	7,0	49	80	8,6	6,5
Maximum	300	10,3	67	100	5,6	9,4
Minimum	60	5,5	24	40	10,7	5,6
Lithuania						
Mean[2]	210	8,4	37	75	8,1	8,9
Maximum	1080	12,2	67	100	10,7	12,5
Minimum	40	5,5	14	40	4,9	5,6

[1] Completely deteriorated gravel pavement was found in two spots of two different test sections of Kaišiadorys district.

[2] Estimation based on results from all test sections.

the practices of paving gravel roads in Lithuania and experience of other similar climate countries (e g Russia, Finland and the State of Minnesota, USA), three the most common in Lithuania types of asphalt pavement structures were selected for estimating pavement construction costs. Type No 1–7 meters width, 6 cm thickness asphalt concrete 0/16-V_n base course with a 12 cm thickness crushed dolomite subbase and a minimum of 8 cm thickness levelling course of enriched gravel. Economic construction cost of this type of pavement under 1996 price level was 288,3 thousand Litas (83,5 thousand €) per kilometer and average yearly roughness was 3,5 m/km IRI. Type No 2: 6 meter width base course of double surface dressing with crushed dolomite, 12 cm thickness subbase of gravel stabilised with cement and emulsion and a minimum of 8 cm thickness levelling course of enriched gravel. Economic construction cost of this type of pavement under 1996 price level was 143,4 thousand Litas (41,5 thousand €) per km and average yearly roughness was 5,5 m/km IRI. Type No 3: 6 m width, 4 cm thickness asphalt concrete 0/11-V base course, 12 cm thickness subbase of gravel stabilised with cement and emulsion and a minimum of 8 cm thickness levelling course of enriched gravel. Economic construction cost of this type of pavement under 1996 price level was 238,6 thousand Litas (69,1 thousand €) per km and average yearly roughness was 3,5 m/km IRI. Pavement types were based on real projects of laying asphalt pavements on existing gravel roads. The assumption was made that analysed gravel roads should meet the requirements of design standards and no reconstruction is required.

Paved road maintenance expenses were estimated as an average of Ukmergė, Kaišiadorys and Kelmė districts expenses for maintenance of paved regional roads. Based on survey of maintenance expenses, the assumption was made that paved road routine maintenance does not depend on traffic volume and equals the economic cost of 2,2 thousand Litas (637 €) per km per year under 1996 price level. Time periods between repairs and repair costs were taken from Standard requirements and price catalogues. Because there was no local data on the repair periods of the second and third asphalt pavement structure types, the required data were taken from the countries with similar climatic conditions (Finland and the State of Minnesota, USA), where such pavement types were applied earlier.

Savings in gravel road maintenance expenses were estimated as an average of Ukmergė, Kaišiadorys and Kelmė districts expenses for maintenance of regional gravel roads. Based on survey of maintenance expenses, the assumption was made that starting from AADT of 200 vpd gravel road routine maintenance expenses (1,1 thousand litas (319 €) km/year) increasing one fourth for each 100 vpd and equals the paved road routine maintenance expenses at AADT of 600 vpd. Additional expenses for blading allow to keep the average pavement roughness throughout all blading season (approx 8–9 months). Time periods between repairs were used according to Standard requirements and existing practice. Repair costs were estimated according to local price catalogues.

2.1.4. Economic research

Economic research instead of financial or any other kind was obviously chosen because it concerned public costs and benefits appraisal.

Economic research comprised of two parts: 1) analysis and approval of the most appropriate economic feasibility evaluation methods and criteria, 2) selection of road investment appraisal components.

Research of economic feasibility evaluation methods and criteria concluded that under limited budget conditions the IRR should be selected as the most important criteria for the decision making on paving of gravel roads. The secondary recommended criteria were: NPV and Construction Cost. A 20-year road investment appraisal period, discount rate of 10 % and annual AADT increase in 7 % were accepted for the model calculations.

Substantiation of road investment appraisal components was based on their importance and current scientific reliability of monetary valuation possibilities. It was concluded that 6 components are to be included into the Lithuanian model for economic evaluation of the feasibility of paving gravel roads. Two of the components were representing key costs and the rest four – major benefit components. These were:

- pavement construction costs,
- paved road maintenance expenses,
- savings in gravel road maintenance expenses,
- savings in VOC,
- savings in journey time,
- benefits from minimisation of dust and other environmental pollution.

The first 3 components were explained under the Road Engineering Research paragraph. The last 3 components are closely related to transport economy. They are shortly presented below.

Savings in VOC were calculated by the VOC Sub model Version 4.0 of the World Bank Highway Design and Maintenance Standards Model HDM-III, with an input of the required data on local vehicle fleet, measured road and traffic parameters. Savings were computed as a difference between VOC on existing gravel road sections versus VOC on more even paved roads. It was assumed that traffic flow and the composition of different vehicle types do not change after paving.

Savings in journey time were estimated using the curves of relationship between travel speed and road roughness on gravel and earth roads presented in the World Bank HDM-III model and locally accepted relationships between vehicle speeds (or allowed speeds) and roughness on paved roads. The difference of speed on the same gravel and paved road sections resulted in a certain amount of time savings, which were expressed in monetary terms. Data required for estimating journey time savings consisted of AADT, traffic flow composition, vehicle occupancy rates and data on working and non-working time for occupants of different vehicle types. It was assumed that the traffic flow composition as well as vehicle occupancy rates should be the same before and after paving a gravel road.

Benefits from minimisation of dust and other environmental pollution were estimated using programme EKOL. The programme assessed impacts of negative transport-generated pollution on human health, industry, public utilities and plantings in money terms. The following pollution components were assessed: noise, CO, NO, C_xH_y, SO_2, Pb, B(a)p, inorganic compounds and solid particles. Programme output depended on AADT, traffic flow composition and the type of roadside surroundings. The type of an average for Lithuania gravel road surroundings reflected the research on roadside surroundings data collected in test regions. The average Lithuanian roadside surroundings, AADT equal to 300 vpd and a gradient equal to 0 % were used for model calculations. Based on the data of research and publications done by British, Finnish and Lithuanian scientists, it was assumed that the sum of losses generated by more frequent vehicle speed changes under rough gravel road conditions, a more rapid deterioration of vehicle parts and losses generated by dust impact, on gravel roads were 1,2 time bigger than that on paved roads with the same AADT and traffic flow composition.

2.2. KAMIS model and structure

The essence of the model was relatively simple. Six interacting cost and savings sub-models were added together over a 20-year period in discounted present values with unit costs determined at 1996 prices.

Creation of the mathematical model for evaluating an economic feasibility of paving gravel roads was founded on the principles of reliability, simplicity and applicability.

Main model parts are 6 major data sets, 6 sub-models representing 2 cost and 4 savings components and the stage of cost/benefit analysis (Fig 1). 6 major data sets comprise a total of 15 minor data sets, which total 79 data set elements (excluding HDM and E Data Set elements). Initial model computations were based on running the model with an application of the 3 different values to the 3 data set elements – AADT of a gravel road to be paved, gravel road roughness and asphalt pavement type to be applied. These elements were called independent variables. The values of these variables:

- AADT of a gravel road to be paved: 200 vpd, 500 vpd, 800 vpd;
- gravel road roughness: 5 m/km IRI, 8 m/km IRI, 11 m/km IRI;
- asphalt pavement structure types: type No 1 (average yearly roughness – 3,5 m/km IRI), type No 2 (5,5 m/km IRI), type No 3 (3,5 m/km IRI).

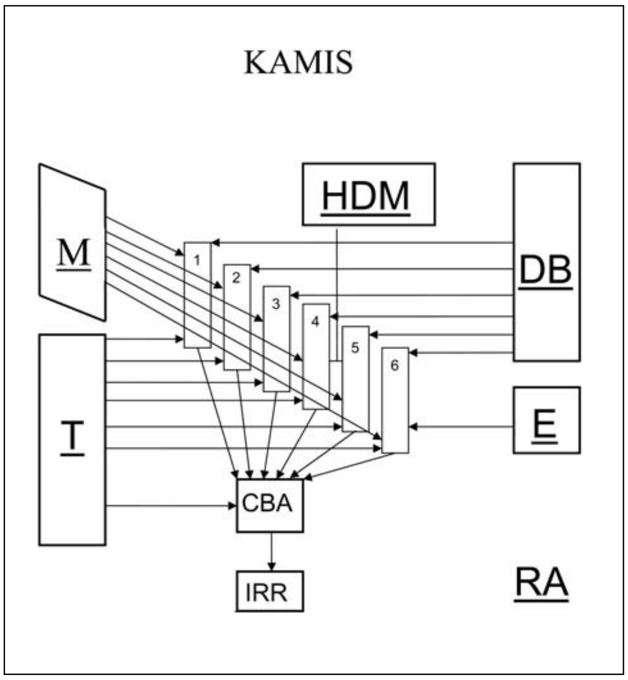

Fig 1. Scheme of KAMIS model computations algorithm under the limited budget conditions [1]:

T – paving timing and economic valuations criteria data set; M – measurement data set; HDM – HDM data set; DB – unchangeable data bank; E – evaluation of environmental issues data set; RA – model application restriction area data set; CBA – cost/benefit analysis; IRR – internal rate of return; 1 – cost sub-model for determination of pavement construction cost; 2 – cost sub-model for estimation of paved road maintenance expenses; 3 – benefit sub-model for estimation of gravel road maintenance expenses; 4 – benefit sub-model for computation of VOC savings; 5 – benefit sub-model for determining journey time savings; 6 – benefit sub-model for computation of benefits from minimisation of dust and other environmental pollution

Independent variables influenced dependent variables which were functionally connected with the first five sub-models and were used for estimating data for input into the cost/benefit analysis stage of KAMIS model. In initial model computations a main seekable the IRR maximum value. KAMIS – the name of the model is coming from the Lithuanian abbreviation Kelių Asfaltavimo Modelis (the closest meaning in English would be – Road paving model). As well first letter **K** represents the location where model was built – Kaunas (location of TRRI) and the last letter **S** is the first letter of the name of the author – Skirmantas Skrinskas. KAMIS scheme is presented in Fig 1.

2.3. KAMIS model testing results

The model estimated and compared renovation expenses and savings based on road technical condition, road pavement roughness and traffic parameters. In comparison with other well-known models or systems, currently used for appraisal of paving of gravel roads, KAMIS model evaluates a wider range of cost and benefit components included (first of such kind of models in the world included environmental improvement assessment) and first which was applicable under "freezing climate" conditions.

Running of the model allowed:

- to evaluate the economic feasibility of paving gravel roads, meeting the requirements of design standards, from the road maintenance, road users and environmental point of view,
- to define the threshold value between those gravel roads where paving is feasible and those where asphalt pavement is not justified,
- to monitor operating costs of different vehicles and the time losses of their passengers in various road sections or routes.

The IRR was grounded to be the most important criteria for the decision-making on paving gravel roads under the limited budget conditions. Secondary recommended criteria were: NPV, construction cost and cost/ benefit ratio.

KAMIS model was implemented and was used in several organisations of Lithuanian Road Administration (LRA, Regional Road Administrations and State Enterprise "Transport and Road Research Institute") since 1997. Good model testing results supported its international presentation to scientific society in 1998 under the PhD Thesis framework of VGTU. The creation of the model had an impact on developing the state strategy of paving gravel roads in Lithuania and served as a basis for its economic justification [2].

Easy model application enabled Lithuanian Road Administration with assistance of TRRI to select the most feasible for paving gravel road sections and in cooperation with the World Bank still the same year to find financial donors (European Investment Bank). Still the same year public tender was announced and Lithuanian gravel roads paving programme for years 1998–2000 was started.

3. Lithuanian gravel road paving programme implementation

Eight full years of continuous gravel road paving has already passed since 1998 and another three year Programme from 2006 to 2008 is on the way. This article has no aim in analysis of engineering data input, but stresses on analysis of a Programme economic consequences. Summary of a few key evaluation criteria is presented in Table 2.

Changes of KAMIS output results were related not only to the decrease of the traffic flow on gravel roads for the reason that the most intensive ones were already paved. Deeper look in how the model cost and benefit components changed during the program implementation period enables to estimate the difference between theoretic and real selected key economic valuation criteria – NPV and IRR.

4. Analysis of the change of variable values which effected NPV and IRR in the period of 1998–2006

This section describes main changes of situation on Lithuanian gravel roads since 1997. KAMIS input data for programme calculations of 1998 was based on the fixed 1997 year costs. Some data was collected even earlier. Those were the reasons why the presented comparisons are made with the base year of 1997 figures.

Table 2. Change of a few representative Lithuanian gravel roads paving programme input data and outcoming results estimated by KAMIS during the programme implementation stages in 1998–2008

According to the programme												
Paving programme, year	Paving works	Cost, mill Litas		NPV, mill Litas per km			IRR, %			Discount rate, %	AADT increase, % per year	IRI of gravel roads, m/km
	km /year	Construction cost	Average 1 km cost	Average	Min	Max	Average	Min	Max		Forecast	Average
1998	274,9	84,4	0,34	0,67	0,18	1,92	33,7	15,3	79,5	10	7	11
1999	329,9	121,7	0,36	0,57	0,01	1,66	29,3	10,2	67,3	10	7	12
2000	328,9	133,6	0,41							10	7	12
2001	–	–	–	–	–	–	–	–	–	–	–	–
2002	105,6	48,1	0,44	0,55	0,02	1,71	16,2	5,8	33,7	5	5	11
2003	215,0	103,7	0,48	0,43	0,07	2,06	13,4	1,3	37,5	5	5	11
2004	146,0	148,5	0,54	0,58	0,06	1,19	16,4	5,7	34,1	5	3	10
2005	231,3	143,9	0,51	0,49	0,02	2,27	17,2	5,7	53,9	5	3	10
2006	53,7									5	3	11
2007	323,4	191,0	0,59	0,29	0,01	0,90	11,9	5,3	75,5	5	3	11
2008										5	3	11

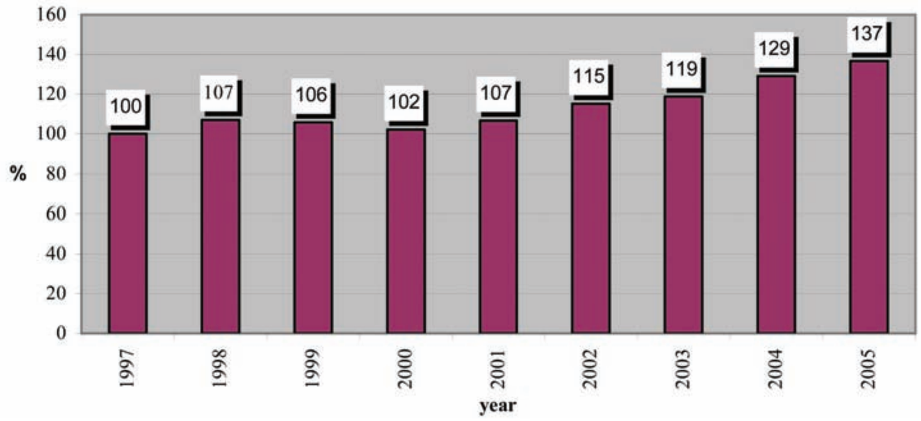

Fig 2. Changes of traffic volume on Lithuanian state roads

Changes of traffic volume on Lithuanian state roads in 1997–2005 are presented in Fig 2.

The road traffic volume on regional roads in 2005 increased by 32 % compared to 1997, but Russian economic crisis has resulted in overestimation of an accepted 7 % yearly growth of traffic flow and NPV and IRR correspondingly.

Changes of average traffic composition on gravel roads are presented in Table 3.

The table shows that during one decade the traffic composition changed dramatically: the share of light traffic (cars, minibuses and light trucks) increased from 65 % to 85 %, while the share of heavy traffic decreased from 35 % to 15 %. At present the traffic composition on Lithuanian rural roads is similar to that of West European countries. The decrease of share of heavy traffic led to not so fast deterioration of gravel roads. As well it corresponded to the decrease of real versus theoretic Programme NPV and IRR. It also should be stressed that traffic data was the only factor having minimisation effect for theoretically estimated NPV and IRR results.

Other factors described below had a long term maximisation effects.

On the basis of model assumption average asphalt pavement roughness during the analysis period should correspond to 3,5 m/km, IRI. Nevertheless, the measurements in most cases show that roughness is less in comparison to the limits indicated. An average roughness of paved gravel roads in Lithuania makes 1,78 m/km, IRI. According to the construction recommendations, roughness of paved regional roads should be < 2,5 m/km. (The same figure – 2,5 m/km, IRI – was initially used as starting digit of a typical paved roughness regression curve applied in KAMIS). Instead of a average paved road roughness of 3,5 m/km, IRI (used at > 90 % of all km paved) 2,0 m/km average paved road roughness is to be applied instead and the theoretic and factual paved road roughness result was re-estimated.

Construction cost is the other key influencing variable after traffic flow parameters and pavement roughness. Construction cost start the analysis variation of all cost and benefit components.

The pavement structure and technology remained the same during 1997–2006. Type No 1 was the most common. The average paving costs of 1 km gravel road are presented in Table 4.

The average increase in construction costs comparing 2005 to 1997 was about 50 %. The growth in 2006 resulted to 12 %. The forecast of construction costs growth in 2008 comparing to 2006 is 10–12 % due to materials, labour as well as additional reconstruction and land purchase costs.

After 8 years from the beginning of the gravel road paving programme it is possible to analyse and systematise the variation of accident rate. After road paving driving conditions became better, the probability of accidents due to mean visibility in dust decreases as well as road

Table 3. Changes of traffic composition in 1995–2005

Vehicle type	Share in the total traffic, year 1995, %	Share in the total traffic, year 2005,%
Car	52	74
Minibus	5	6
Bus	3	1
Light 2-axle trucks	8	5
Medium 2-axle trucks	26	7
Heavy 2-axle trucks	3	4
3-axle trucks	2	2
4- and 5-axle trucks	1	1

Table 4. Changes of construction costs

Width of asphalt concrete pavement, m	Year 1997, economic costs, thousand Litas	Year 2005, economic costs, thousand Litas	Year 2006, economic costs, thousand Litas
6	282	427	479
7	329	486	545

Table 5. Changes of maintenance costs

Type of pavement	Type of maintenance	Year 1997, economic cost thousand Litas	Year 2005, economic cost thousand Litas
Gravel	Routine maintenance	1,2	1,5
	Overlay, 8 cm gravel	25,8	47,0
Asphalt concrete	Routine maintenance	2,5	3,0
	Surface dressing with a levelling layer	45,0	82,7

Table 6. Changes of VOC

Vehicle type	IRI, m/km	Year 1997, Litas per 1000 veh km	Year 2000, Litas per 1000 veh km	Year 2006, Litas per 1000 veh km
Car	2,0	379	503	715
	4,0	413	566	808
	9,0	506	733	1054
Medium 2-axle truck	2,0	1217	1577	2238
	4,0	1272	1673	2380
	9,0	1480	1984	2838

Table 7. Changes of journey time value costs

Year 1997, Litas per veh hour	Year 2005, Litas per veh hour	Year 2006, Litas per veh hour
13,1	21,9	24,2

Table 8. Changes of benefits from reducing of environmental pollution after paving

Type of area	Year 1997, savings, thousand Litas	Year 2005, savings, thousand Litas	Year 2006, savings, thousand Litas[1]
Non-residential	0,3	0,4	10,9
Residential	6,0	6,5	34,6

[1] The changes to sub-model EKOL were applied. Since 2006 benefits from minimisation of dust and other environmental pollution includes not only the influence on human health and plantings but also the costs of real estate.

Table 9. Comparison of costs increase in 1997–2006

Component type	Component name	2006 compared to 1997, increase in %
Cost	Construction cost	68
	Routine maintenance of paved roads	47
	Periodic maintenance of paved roads	93
Benefit	VOC	93
	Time value costs	85
	Ecological cost (for average area)	900
	Routine maintenance of gravel roads	52
	Periodic maintenance of gravel roads	92

transport driving speed. One of the main reasons of car accidents is exceeding the speed permitted. It is offered to analyse the difference of accident rate in paved regional roads, determine reasons of accidents and possible losses as well as to determine appropriate means for improving traffic safety and to include it in construction costs.

The average maintenance costs of 1 km gravel and paved road are presented in Table 5.

Here we see rather small increase of maintenance costs – by 17–20 % and big increase in repair costs – by 80 % and more. Small increase of maintenance costs is partially related to a lesser deterioration of roads comparing to previous years as well as decreased share of heavy traffic, which causes major damages. The forecast of maintenance costs growth during 2006–2008 is 4–5 % per year and is related to labour and material costs growth.

The average VOC for 1000 veh km of typical traffic composition for years 1997, 2005 and 2006 are presented in Table 6.

The Table 6 shows that during 1997–2006 the value of VOC increased by about 2 times. Changes of time value costs for vehicle hour of typical traffic composition are presented in Table 7.

The increase of time value by 67 % is mostly related to the growth of salaries and bus tickets prices. The small share of increase is related to the change of calculation methodology – the cost of cargo time is included into time value costs for year 2005 and later.

Changes of benefits from reducing the environmental pollution after paving for 1 km/year of road are presented in Table 8 (for AADT 200 vpd).

The comparison of costs and benefits growths shows that construction and maintenance costs during 1997–2006 increased not so much comparing to the benefits costs growth. The growth of costs and benefits is presented in Table 9.

Of course, general cost and benefit components value change does not directly effect NPV and IRR. It depends on the value weight in CBA. Taking into account that until 2005 environmental saving rarely exceeded 2 % of all gains and both paved and gravel road maintenance expenses were adequate to each other both in the value growth and weight, it is estimated that the volume of benefit components were growing by 21 % more than costs components. This growth was as well higher that the planned discount factor accumulation by nearly 40 % and even more than the real cumulative inflation – 78 %. The increase of real benefit component values versus theoretic ones could be understated in comparison with real and theoretic NPV and IRR. The calculation of 100 % correct results is to be done after getting final data for the whole analysis period. That would be clear only in about 20–21 year after paving last gravel road planned in the Programme. The longest and correspondingly the most reliable and justifiable analysis period has

Table 10. Comparison of theoretic and real NPV and IRR results calculated correspondingly in 1997–1998 and in 2006

Paving year	Average NPV, mill Litas per km			Average IRR, %		
	Calculated theoretically	Factual current estimation	Changes in %	Calculated theoretically	Factual current estimation	Changes in %
1998	0,67	0,75	+12	33,7	35,7	+6
1999–2000	0,57	0,68	+19	29,3	31,9	+9
Average	0,60	0,70	+17	30,6	33,0	+8

the first stage of the implementation of the Lithuanian Gravel Roads Paving Programme for years 1998–2000. Estimation results are presented in Table 10.

After the assumption that gravel road roughness is stable and equal to 11 m/km, IRI, we come to the conclusion that the growth of Lithuanian economy and increase of living standards resulted in an economically based decrease of AADT required to pave gravel road section.

The changes presented above led to the situation that sections profitable to pave had less and less traffic. The AADT of typical section when paving is profitable (i e IRR > 10 %) at an average gravel road roughness of 11m/km, IRI is presented in Table 11.

The increase is double in non-residential area and threefold in residential environment. It represents a shift from the budget restricted society into a quality valuating society.

Table 11. Changes of required AADT for gravel road paving using model KAMIS

Year	AADT (non-residential area)	AADT (residential area)
1997	> 300	> 240
2000	> 250	> 180
2003	> 220	> 150
2006	> 150	> 80

5. Conclusions

1. During the implementation of Lithuanian Gravel Road Paving Programme during the period 1998–2005, 1631,6 km of gravel roads were paved. 758 million LTL (219,5 million €) were used for the Programme investments. 35 % of invested funds was state funding and 65 % of investments came from foreign investors. The KAMIS model was used in preparation of investment projects and proved to be effective tool for justification of gravel roads paving.

2. The total Programme implementation NPV determined by KAMIS from 1998 up to the end of 2005 accumulated 908 million LTL (263 million €).

3. The decrease of AADT on gravel roads to be paved led to the decrease of NPV: average theoretical NPV of paving of 1 kilometre of gravel road in the Programme of 1998 amounted to 670 thousand Litas, in the period from 1999 to 2000 amounted to 570 thousand Litas, in the period from 2001 to 2004 average NPV decreased to 500 thousand Litas; in 2005–2006 programme it was 490 thousand Litas. In the 2007–2008 Programme NPV has dropped to 290 thousand Litas. In the period from 1998 to 2008 average theoretic NPV per kilometre of paving of gravel road has dropped by 2,3 times (or on average 20 % per year).

4. It was found that theoretically calculated NPV is not equal to the real NP value, because of the fast changes in the cost and benefit components as well lower than the forecasted traffic flow, better than initially assumed paved road roughness, less than forecasted state inflation, additional probable benefits arising from paving.

5. Based on KAMIS model theoretic NPV calculations and data collected during the Programme implementation, it is proven that real NPV is considerably higher than that of a theoretic one.

Influences limiting real NPV result in 8 years of the Programme implementation were:

- on average 17 % less AADT volumes growth than forecasted,
- triple decrease of light and medium 2-axle trucks in the traffic flow in regional roads.

Influences increasing real NPV result in 8 years of the Programme implementation were:

- 29 % better average paved road roughness than it was assumed in the applied in KAMIS roughness progression model,
- 21 % higher growth of major benefit components versus key cost component; and longer time of exposure of increased benefit components,
- 19 % less accumulated interest rate in comparison with the used discount factor.

6. The calculation results show that factual current CBA estimations comparing to theoretic ones for the Lithuanian Gravel Roads Paving Programme for years 1998–2000 are as follows: NPV by 17 % higher than the theoretic one, IRR by 8 % higher.

7. The growth of Lithuanian economy and increase of living standards resulted in an economically based decrease of AADT required to pave gravel road section. The required minimal AADT dropped from AADT 300 vpd to 150 vpd for non-residential area, and from 240 vpd to 80 vpd for residential area in 1997 and 2006 correspondingly.

8. KAMIS paradox states that the greater accuracy and the range of costs and benefits components in feasible investment projects, the higher values CBA gives for both

theoretic and factual NPV, IRR and B/C ratio results. The numerical growth of figures can be somewhat steady or explosive, depending on the latest proven and monetary valuable findings which could be included into the model. As it happened in KAMIS in 2005 with an inclusion of cargo time value and extra accountable environmental/real estate benefits in 2006.

9. Fast cost and benefit components growth shows that in fast growing economies traditional CBA calculation scheme gives a programmed bias. The bias comes from the proven fact that both costs and benefits, as well as state GDP grow faster than inflation (or planned discount factor). Further research is needed for findings to be applied in KAMIS or elsewhere.

10. General authors' forecast after weighing all estimated changes and today's trends is to apply a 20 % increase factor for calculating a real NPV of Lithuanian Gravel Roads Paving Programme. It means that expected real NPV of projects implemented in 1998–2005 is 1,09 billion LTL (316 million €).

11. Nevertheless, the authors want to state that despite the continuous economic growth a certain share of gravel roads in the state road network should obligatory be kept. Because it is a part of the country's history and heritage. Situated on an edge of the last glacier Lithuania is rich in gravel resources and a bit dusty gravel road is a usual part of our traditional landscape and folklore. Most picturesque low volume gravel road sections and "ringroads" have as well to be selected and protected at an early stage of Lithuanian Gravel Roads Paving Programme.

References

1. SKRINSKAS, S. Research of the Condition of Lithuanian Gravel Roads and Feasibility of their Renovation. Summary of Doctoral Dissertation. Sciences of Technology, Civil Engineering (02T). Vilnius: Technika, 1998. 32 p.
2. SAKALAUSKAS, K.; SKRINSKAS, S. Lithuanian Gravel Roads and Feasibility of Their Paving. *Statyba* (*Civil Engineering*), Vol IV, No 2. Vilnius: Technika, 1998, p. 134–141.
3. SKRINSKAS, S.; PUODŽIUKAS, V. Investigating the calibration of the Russian unevenness measuring device PKRS-2u according to the International Roughness Index (IRI). In: *Roads and Bridges* (*Keliai ir geležinkeliai*). Proc. 2nd Intern Conf "Cities Engineering and Environment". Vilnius: Technika, 1996, p. 98–100 (in Lithuanian).
4. DVARECKAS, V.; SKRINSKAS, S. Influence of the Middle Lithuanian geomorphological conditions on gravel roads. *The Geographical Yearbook* (*Geografijos metraštis*), Vol XXI. Vilnius: Institute of Geography. Lithuanian Geographical Society, 1998, p. 250–259 (in Lithuanian).

Submitted 3 Oct 2006; accepted 14 Nov 2006