Maintenance costs of public roads: Do empirical data confirm the superiority of concrete over asphalt?

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Koszty utrzymania dróg publicznych: czy dane empiryczne potwierdzają wyższość betonu nad asfaltem?

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Streszczenie

Jedną z najważniejszych zasad zarządzania infrastrukturą jest stosowanie metod wyceny kosztów inwestycji w cyklu życia. Takie podejście, nazywane LCCA (z ang. life-cycle cost analysis – ocena kosztów w cyklu życia), jest promowane między innym przez amerykańską Federal Highway Administration. Stawia ono warunek, że decyzje co do wyboru technologii wykonania planowanej inwestycji powinny uwzględniać prognozę kosztów generowanych przez dany obiekt na przestrzeni założonego okresu życia budowli.

Zasadnicza część istniejącej literatury na ten temat opiera się na teoretycznych kalkulacjach, które – pomimo zachowania rygorów naukowości – nie zawsze wiernie oddają rzeczywiste koszty eksploatacji nawierzchni. Do wyceny kosztów utrzymania służą również publicznie dostępne kalkulatory, tj. kanadyjski CANPav™ (Ready Mixed Concrete Association of Ontario & Cement Association of Canada, 2014) lub polski Kalkulator drogowy (DROCAD Sp. z o.o., 2014), ale również operują one na pewnych założeniach, które nie zawsze pokrywają się z rzeczywistością.

Celem niniejszego studium było zebranie danych o autentycznych kosztach budowy i utrzymania dróg publicznych w technologii asfaltowej i technologii betonowej. Wykorzystano do tego celu dane historyczne obejmujące zamówienia publiczne w gminie Grybów, będącej jedną z niewielu jednostek samorządowych w Polsce, która zleca budowę dróg w obu technologiach. Mimo ograniczonego zakresu analizy, jest ona krokiem naprzód w stosunku do prowadzonych dotychczas czysto teoretycznych rozważań, gdyż nie tylko uwzględnia realne poziomy cen, ale również podejmuje temat dróg betonowych o charakterze lokalnym, który w literaturze przedmiotu jest często pomijany na rzecz dróg betonowych o wyższych kategoriach ruchu.

Analiza wykazała, że dla 30-letniego okresu życia drogi, przy bardzo ostrożnych założeniach co do wysokości stopy dyskontowej, wysokości stopy inflacji oraz zakresu i częstotliwości napraw, nawierzchnia betonowa wciąż jest rozwiązaniem bardziej ekonomicznym niż nawierzchnia bitumiczna. Dla reprezentatywnego odcinka drogi, wartość bieżąca netto przyszłych przepływów pieniężnych związanych z jego eksploatacją była o 5,67 proc. niższa w przypadku zastosowania technologii betonowej. Przy zastosowaniu klasycznych założeń, oszczędność w cyklu życia mogłaby wynieść nawet 33-35 proc.

Abstract

One of the cornerstones of far-sighted infrastructure management is that it involves a life-cycle consideration, as endorsed notably by the U.S. Federal Highway Administration. Decisions on investments should be considered in terms of product performance over time. In spite of the initial construction cost, all constituents of maintenance (i.e. cost to be borne during road's assumed lifespan to keep the specified service level) should be quantified to equip the public investor with full information on pavement's long-run prospects.

The major part of the existing research in this field rests on theoretical calculations which, although sound and scientifically rigid, may not always translate accurately to the actual wear and tear of pavements. Maintenance costs are also delivered to the broad public by tools like Canadian CANPav™ (Ready Mixed Concrete Association of Ontario & Cement Association of Canada, 2014) or Polish *Kalkulator drogowy* (DROCAD Sp. z o.o., 2014), none of which is faultless.

This paper aims to apply the real life statistics on concrete versus asphalt construction costs, assembled from the commune of Grybów in southern Poland. Despite limited time series, it is still instructive to cast a closer glance at these few actual figures instead of proving concrete pavements' long-term advantage on the basis of theoretical or anecdotal evidence. Moreover, the paper addresses the underestimated issue of local concrete roads that often gives way to more rewarding research on high-traffic-volume concrete pavements.

The analysis revealed that for a 30-year horizon, given very conservative assumptions as to the discount rate, inflation rate, and the scope and frequency of pavement rehabilitation, concrete pavements are still more economical relative to bituminous pavements. For a representative road section, the net present value of future cash flows related to its maintenance was 5.67% lower in PCC concrete technology. The life-cycle saving may go up to as much as 33-35% when excessively cautious assumptions are lifted.

1. Introduction

1.1 General context and motivations of the study

According to the figures assembled by the Poland's Central Statistical Office (GUS), the local roads market was worth 12.85 billion PLN in 2012. This is the sum of annual investment in this field and it boils down to nearly 3 billion PLN for roads in counties (*powiaty*), nearly 5 billion PLN for roads in cities with county rights (*miasta na prawach powiatu*) and slightly more than 5 billion PLN in communes (*gminy*). When roads managed by voivodeships (*województwa*) are added to this landscape, this amount grows further by approximately 3.5 billion PLN. The public roads network in Poland was 364,986.8 km at the end of 2011. While 91% of county roads are hard-surfaced, this ratio for communes reaches only 49%. It lets us assume that there is a promising potential for future investments.

Poland's local roads do make up a homogenous class, but whereas their condition varies depending on road category and geography, it is generally considered substandard. In its recent report, Poland's Supreme Audit Office (NIK) (2014) has generally assessed that the condition of local roads is poor, but failed to provide more detailed data on the magnitude of problems. It also criticized the chronic negligence in the realm of planning of road network development. 20 out of 35 territorial governments that have been scrutinized in this respect did not manage to develop such blueprints, despite the formal requirement. As a consequence, political authorities exhibit a tendency to decide arbitrarily and on a case-by-case basis on the investment priorities.

Nevertheless, it is also not wise to assume that local roads are repaired as soon as they really need it. The bituminous roads degrade quicker than municipalities are able to rehabilitate them. 29 out of 35 NIK-controlled authorities failed to ensure proper diligence when assessing the condition of the road network under supervision, or failed to carry out such a revision at all.

Reflecting on the above mentioned quality issues and keeping in mind the huge amount of financial resources that are expended every year to sustain the local roads' network in Poland, the motivation of this paper is to raise the policy makers' awareness of the LCCA methodology. It concerns both the public investors at the level of territorial governments and the central institutions who oversee two most important financial facilities aimed at the local roads' development and rehabilitation: the National Local Road Reconstruction Programme (NPPDL), amounting to ca. 0.5-1 billion PLN annually, and the funds known formerly as FOGR (Agricultural Land Protection Fund), totaling ca. 100 million PLN annually.

1.2 Life-cycle cost analysis

The life-cycle dimension in infrastructure displays itself in two metrics: life-cycle cost analysis (LCCA), which is more of an economic nature, and life-cycle assessment (LCA), which focuses on a womb-to-tomb examination of environmental impact (Milachowski, Stengel, & Gehlen, 2011). One of the most appropriate and fruitful applications of both LCCA and LCA approaches is possible in the domain of infrastructure. This particular research restricts itself solely to the pecuniary LCCA component.

The legal environment in Poland gave birth to the phenomenon that winners in public tenders are predominantly determined by price as the sole criterion. Poland's public procurement regulations have never been effective in introducing the LCCA method, which is widely used in the Anglo-Saxon culture and Western Europe (Bianchi & Guidi, 2010, pp. 151–164; Hall et al., 2007, pp. 25–30; IPWEA, 2011). Despite many publications underscoring the contribution of concrete technology to superior LCCA, it is endorsed neither by the relevant ministry, nor by the General Directorate of National Roads and Motorways. However, employing LCCA is technically possible under art. 91 pt. 2 of the Public Procurement Act, which enlists the optional criteria to be used by public investors when assigning scores to bids.

Another consideration is that tenders usually pre-define the materials used in infrastructure projects. There is a rarely used option to set up a so-called „open" tender (also known as an alternate design & alternate bid, or a two-component bid), in which contractors decide to bid for one out of two technologies put forth by an investor. The tender itself determines which bidder is more attractive. However, in most cases, it is the investor or her road designer who imposes a single technology. It goes without saying that asphalt is then the primary choice.

Apart from durability, the predictability of maintenance cost is also important, though often undervalued, factor. Whereas the prices of concrete are relatively stable, the asphalt prices may fluctuate aggressively due to their high sensitivity to the price of petroleum and the currency exchange rate risk. For instance, between October 2008 and May 2013 the prices of road bitumen type 35/50 spiked from 1,575 PLN to 2,010 PLN per Mg in Lotos Asfalt and from 1,360 PLN to 2,040 PLN per Mg in Orlen Asfalt, two major suppliers in Poland (Arcata Partners, 2012). The compound annualized growth rates were 4.46% and 7.53%, respectively. However, the peak of 2,300 PLN per Mg was reached in 2012. By the same token, while type B35 concrete cost 260.32 PLN per cubic meter in the first quarter of 2008, it went up to merely 272.53 PLN in the hottest market period of third quarter 2012 (ORGBUD-SERWIS Sp. z o.o., 2012). This translates to a compound annualized growth rate of as low as 1.02%.

1.3 Grybów commune

The commune (in Polish: *gmina*) of Grybów is a rural setting in Nowy Sącz county, Lesser Poland voivodeship, in southern Poland. Its territory of 153 square kilometers contains the villages and settlements of Biała Niżna, Binczarowa, Chodorowa, Cieniawa, Florynka, Gródek, Kąclowa, Krużlowa Niżna, Krużlowa Wyżna, Ptaszkowa, Siołkowa, Stara Wieś, Stróże, Wawrzka and Wyskitna. The commune's population is nearly 25,000 with ca. 3,000 homesteads.

The commune is thus a typical Polish rural site, with this exception that it is one of the very few *gminas* in Poland that calls for bids in both flexible pavements and rigid pavements. The history of inviting tenders in concrete began in 1997, similarly to several other communes in Nowy Sącz county (Sajdak-Chudzik, 2010) and lasts until now. At present, the transportation network of communal roads reaches 550 km, with roughly 90 km of concrete roads and 110 km of asphalt roads. The remaining 350 km are either soil-stabilized or made of crushed stone (ca. 250 km) or dirt roads (ca. 100 km).

Concrete technology soon became preferred choice for hard-surfaced pavements, particularly in steep terrain where constructing a bituminous road is troublesome, and where the risk of devastating floods is evident. According to the commune's spokesperson, the extended durability of concrete is worth higher prices. However, the commune did not close the door for asphalt technology completely, thanks to which a comparable analysis can now be executed. The reason for this dualism stems from the observation that in some densely populated areas the grade line of a road cannot be raised and full trenching is deemed too expensive. When this is the case, thinner asphalt overlay is applied instead of a thicker concrete slab. Another limitation occurs when traffic cannot be easily diverted from the reconstructed section to allow for the laborious and time-consuming concrete hardening process. However, this downside might be easily dealt with by the application of roller-compacted concrete instead of a conventional PCC pavement.

This brings us to considering the typical construction process in the commune. More often than not, it starts with the initial work aimed at the improvement of stabilization or sub-base that is performed by local inhabitants in the form of public works. Materials and transportation services are subject to separate tender procedures. Therefore, the investment-oriented tenders often involve just the erection of road's upper layers, using the professional machinery.

2. Literature survey

MIT Concrete Sustainability Hub defines life-cycle as everything between construction and demolition, including: materials (extraction, production, transportation), construction (equipment, traffic delay, transportation), use (rolling resistance, carbonation, albedo, lighting, leachate), maintenance (materials phase, construction phase), end of life (equipment, landfilling, recycling/reuse, transportation) (MIT Concrete Sustainability Hub, 2011). Particularly the recycling stage is often ignored, in spite of promising examples of successful renovation of concrete pavements (ASAMER, 2012). The engineers from University of Texas identify the components of LCCA calculation as follows: pavement performance and distress; costs of construction, maintenance and rehabilitation; travel time delay; vehicle operating costs; emissions; accidents; discounting costs to the present time; reliability (Wilde, Waalkes, & Harrison, 1999, p. 139).

All available comparative studies support the verdict that concrete pavements are more economical in the long run than bituminous pavements. Numerous publications look at LCCA from the perspective of infrastructure in general and concrete roads in particular (Akbarian & Ulm, 2012; Cole, n.d.; Ochsendorf et al., 2011). Federally funded studies in the United States show that concrete interstate pavements cost from 13% to 28% less in the long run than its asphalt equivalent (Concrete Paving Association of Minnesota, n.d.). Similar studies have been carried out in Iceland (Scheving, 2011), and also in Poland (Jackiewicz-Rek & Konopska-Piechurska, 2013), but with no cost quantification.

Nevertheless, the precise quantification of benefits to local concrete roads is rare. Such a study has been conducted in India (Cement Manufacturers' Association, 2006), where due to the nationwide centrally sponsored scheme called Pradhan Mantri Gram Sadak Yojana, construction of local roads is very high on the agenda of the Ministry of Rural Development. This study has shown that life-cycle cost of flexible pavement will be about 19% higher than rigid pavement after 20 years.

3. Methodology

3.1 Research design

The data collection process involved the screening of all road-related tender procedures carried out in the period from 2007 to May 2014. Tenders that involved constructions of a new road, or reconstructions and modernizations of an existing road are listed in Table 1. Furthermore, they are summarized in Table 2. The data collection process was supplemented by an in-depth interview with a representative of the Grybów commune who is in charge of road network management and investments.

Generally, all the roads built between 2007 and 2014, whether in asphalt or concrete, have not undergone any major overhaul until today, despite the sections that have been badly affected by a severe flood that hit Grybów in 2010 and generated ca. 5 million PLN losses in communal infrastructure (Piechnik, 2010). Nevertheless, according to the commune's spokesperson it is clearly perceptible that the asphalt deteriorates more rapidly.

The final product of this paper is the calculation of the net present value (NPV) of all identifiable cash flows associated with the construction and maintenance of a standardized road section. Thus, the asset of this research lies in the implementation of real life pricing data that are only to some extent augmented with the engineering assumptions of *Kalkulator drogowy*. The two main financial inconsistencies of the calculator are that it does not account for inflation and does not discount the future cash flow. Therefore, while it compares asphalt pavements to concrete pavements fairly well and gives a useful hint on what the total ownership costs are, it misrepresents the future expenses by magnifying their importance. As such, it may be considered too beneficial for rigid pavements, whose life-cycle expenses are low. This study attempts to express these figures more pragmatically.

The importance of appropriate inflation accounting for the accuracy of an LCCA exercise is underlined in a number of papers (Asphalt Pavement Alliance, 2011; Lindsey, Schmalensee, & Sacher, 2011; Mack, 2011). According to the Poland's Ministry of Finance, both the projected consumer price index and producer price index for the next years are set at 2.5% (Poland's Ministry of Finance, 2013) which resonates with the assumed inflation target set by the National Bank of Poland. As for the discount rate, 10% is assumed. While it may seem a bit overshoot from the perspective of a territorial government, this will be a true acid test for the sustainability of concrete pavements.

The assumptions with regard to the frequency and scope of reconstructions are set in the Table 3. The concrete road's profile involves 15 cm of PCC concrete over 15 cm of cement stabilized sub-base, while the bituminous road is 4+4 cm of asphalt over 20 cm of crushed stone sub-base. This is more or less suitable for the major part of communal roads in Poland.

3.2 Limitations

It is not possible to be put forth the universal and seamless method of calculating the LCCA. The variety of approaches that co-exist in the homeland of LCCA, the United States, testifies well to this finding (CTC & Associates LLC, 2011). Hence, each LCCA model should be calibrated to incorporate specific local conditions.

There are several reasons of the difficulties to compare life-cycle costs or even construction costs of two alternative technologies. First, the public investor may prefer concrete to asphalt in sites that are exposed to worse conditions, e.g. high volume of traffic, and such projects are therefore more expensive in execution. Second, during the first years after the switch to concrete tenders, the competition among providers of concrete roadways may be low or inexistent. This may drive concrete prices up, unless the sponsor makes use of alternative bid procedure. The competition becomes fiercer after a couple of years of consistent investments in concrete roads. Third, inquiring into exact extent of tenders is extremely time-consuming. Fortunately, the case of Grybów is relatively uncomplicated, as the announced tenders are relatively homogeneous in terms of scope. Nevertheless, at the stage of calculations, it was desirable to oust three observations that may be considered biased: INW.341.29.2010 (asphalt), INW.341.33.2010 (concrete) and INW.341.39.2010 (concrete). All of these projects have been conducted in the year of flood (2010) and involved much accompanying works that were unrelated to the road construction and thus unduly elevated the prices per square meter.

Clearly, a multitude of factors cannot be accounted for in this simplified approach. First, it has not been checked whether the commune Grybów is peculiar relative to other locations in Poland in terms of e.g. extremely cheap concrete transportation cost or the presence of a local company. Second, having no convenient access to tenders published between 1997 and 2006, the development of the concrete roads market could not be traced back to the origins. The practical outcome is that 8-year-long period may be viewed as still too short to authoritatively appraise the long-term quality of an infrastructural object. The projected lifespan of a concrete road is typically set at 30 years, while asphalt roadways need to have the wearing course replaced every 10 years. This study will not imply a huge leap forward in this respect, as these assumptions are taken at face value in the calculation procedure.

It is also important to remember that lower frequency of concrete pavement rehabilitation translates to less fatigue for both road owners and drivers, but this factor is not handily measurable. Similarly, the analysis does not make the effort to quantify the concrete recycling opportunity, leaving this challenge to a follow-up research.

4. Results

It is vital to underline that by employing very careful inputs, as described in section 3.1, this analysis is conservative in three ways. First, it assumes that both concrete prices and road bitumen prices will grow at the same rate, despite the historical evidence of this rate being much higher for road bitumen, both in Poland (Arcata Partners, 2012; ORGBUD-SERWIS Sp. z o.o.,

2012) and globally (Lapointe, 2012; Lindsey et al., 2011). Second, by 10% discount rate, it diminishes the magnitude of future expenditures by probably more than would be sufficient for public entities. Third, some assumptions as to the frequency and extent of reconstructions, which are put forth by *Kalkulator drogowy*, are relaxed in favor of the bituminous technology (see footnotes under the Table 3.). Fourth, we may reasonably expect the lifespan of a well-built local concrete road to be higher than 30 years, whereas flexible pavements generally do not reach such longevity.

In order not to present completely abstract figures, the calculations are made for a reference road of 500 m length and 2.8 m width, which is typical for the commune of Grybów and many other rural settings in Poland. As a construction cost we take the median of 2011-2013 weighted averages, which is 98.85 PLN per square meter in concrete and 70.74 PLN per square meter in asphalt. This is a reasonable benchmark, as the 2014 data set was not comprehensive at the time of submission of this paper, and 2010 was the extraordinary time marked by a giant flood. The ratios showing the relative costs of reconstruction are taken from *Kalkulator drogowy*. The applied horizon is 30 years, but concrete pavements prove to be more cost effective as soon as in the year 10.

The NPV calculations are displayed in the Table 4. All figures should be seen as expenditures, therefore "the less, the better" rule applies.

5. Conclusions

The goal of this paper lies in ensuring that both local and national decision makers and their business partners understand LCCA and gain awareness that it costs money to own a road section and to keep it at a specified service level. The paper enhances the generic results delivered by the only computerized LCCA tool in Polish, *Kalkulator drogowy*, by applying a dose of real life data derived from the experience of Grybów commune.

The Table 4. instructs that concrete becomes competitive yet after the first major overhaul of bituminous pavements, which usually takes place after 10 years of operation. The NPV of road-related expenditures in a 30-year horizon is 5.67% higher for bituminous pavements, all using very orthodox assumptions. Given more realistic assumptions – inflation of asphalt prices at 1 pp. higher than inflation, 7% discount rate, and reconstruction schedule as proposed by the calculator, the life-cycle divergence would mount up to 33-35%. Noteworthy, the communal data show unambiguously that the price difference between both technologies lessens, which is probably the consequence of greater than before competitive rivalry in the concrete roads business.

The figures presented here have reference for the model situation in which the authorities repair roads every time they need it. Unfortunately, the common practice is to procrastinate with removing potholes or with the rehabilitation of rutted asphalt pavement. Since the territorial governments usually lack sufficient financial resources to keep up with the frequency of required reconstructions, this technically leads to the decline in value of assets.

Naturally, the differences in paving or rehabilitation techniques, quality of materials used, as well as other unobservables are difficult to be captured by a quantitative study. Nevertheless, the paper still provides a pronounced and compelling evidence for decision makers to revert their mostly skeptical attitude towards concrete roads in Poland.

This inquiry is expected to stimulate further research in the field, by incorporating different insights and applying them to other jurisdictions. This should also be the signal to kick off with environmentally-driven LCA studies that would be relevant for Polish circumstances. The literature to build upon is rich, indicating concrete roads' supremacy in reduced CO_2 emissions, lower fuel consumption and relieved heat island effect.

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7. Appendices

Table 1. List of road construction tenders in Grybów commune between 2007 and April 2014.

Year	Reference number	Asphalt / Concrete	Natural disaster involved	Winning bid in PLN	Area in square meters	Price per square meter in PLN
2007	INW.341.9.2007	C	Yes	1,327,767.81	16,000	82.99
2007	INW.341.11.2007	A	No	224,480.00	4,000	56.12
2007	INW.341.18.2007	C	Yes	200,417.57	2,131	94.06
2007	INW.341.19.2007	A	No	206,963.24	3,190	64.88
2008	INW.341.7.2008	C	No	1,462,232.11	16,500	88.62
2008	INW.341.16.2008	A	Yes	486,052.14	8,889	54.68
2008	INW.341.20.2008	C	Yes	268,651.95	2,940	91.38
2008	INW.341.21.2008	C	No	209,803.84	2,296	91.38
2009	INW.341.7.2009	C	Yes	379,176.00	4,200	90.28
2009	INW.341.8.2009	C	No	1,354,200.00	15,000	90.28
2009	INW.341.12.2009	A	No	643,232.80	11,000	58.48
2009	INW.341.21.2009	A	No	487,780.40	8,900	54.81
2009	INW.341.29.2009	C	No	230,582.20	2,520	91.50
2009	INW.341.33.2009	C	Yes	517,303.87	5,303	97.55
2010	INW.341.14.2010	C	No	1,665,269.55	17,080	97.50
2010	INW.341.15.2010	C	Yes	83,844.52	910	92.14
2010	INW.341.18.2010	A	No	827,725.59	15,714	52.67
2010	INW.341.27.2010	C	No	136,497.50	1,400	97.50
2010	INW.341.29.2010	A	Yes	317,799.02	1,880	169.04
2010	INW.341.33.2010	C	No	129,417.11	825	156.87
2010	INW.241.35.2010	C	Yes	55,470.96	560	99.06
2010	INW.341.36.2010	C	Yes	360,554.90	3,640	99.05
2010	INW.341.39.2010	C	Yes	943,726.08	7,000	134.82
2011	INW.271.8.2011	C	Yes	2,030,255.53	20,090	101.06
2011	INW.271.9.2011	A	Yes	224,494.68	3,650	61.51
2011	INW.271.14.2011	A	No	667,923.21	9,240	72.29
2011	INW.271.20.2011	C	No	143,484.42	1,400	102.49
2011	INW.271.21.2011	C	Yes	1,087,606.10	10,640	102.22
2011	INW.271.22.2011	A	Yes	189,223.20	2,400	78.84
2012	INW.271.8.2012	A	Yes	155,280.12	2,340	66.36
2012	INW.271.9.2012	C	Yes	1,225,550.64	14,752	83.08
2012	INW.271.12.2012	A	No	317,828.93	5,115	62.14
2012	INW.271.15.2012	C	No	183,260.16	2,240	81.81
2012	INW.271.19.2012	A	Yes	638,001.00	9,950	64.12
2012	INW.271.20.2012	C	Yes	682,637.70	7,560	90.30
2012	INW.271.23.2012	A	No	162,785.58	1,890	86.13
2013	INW.271.12.2013	C	Yes	542,789.22	5,684	95.49
2013	INW.271.15.2013	C	No	1,094,335.92	9,520	114.95
2013	INW.271.16.2013	A	No	626,350.44	6,500	96.36
2013	INW.271.17.2013	A	No	236,542.53	3,310	71.46
2013	INW.271.20.2013	C	No	359,992.60	5,000	72.00

2014	INW.271.9.2014	C	Yes	350,254.80	4,620	75.81
2014	INW.271.10.2014	C	No	1,293,698.87	16,680	77.56
2014	INW.271.13.2014	A	No	629,314.25	9,700	64.88
2014	INW.271.14.2014	A	No	to be decided	4,568	to be decided

Source: own elaboration on the basis of http://bip.malopolska.pl/uggrybow/ and http://www.gminagrybow.pl/.

Table 2. Summary of tenders in Grybów commune. All prices are in PLN.

	Bituminous roads				**Concrete roads**			
	No. of projects	**Total price**	**Per sq. m (weight.)**	**Per sq. m (median)**	**No. of projects**	**Total price**	**Per sq. m (weight.)**	**Per sq. m (median)**
2007	2	431,443	60.01	60.50	2	1,528,185	84.29	88.52
2008	1	486,052	54.68	54.68	3	1,940,688	89.28	91.38
2009	2	1,131,013	56.83	56.64	4	2,481,262	91.82	90.89
2010	2	1,145,525	65.11	110.86	7	3,374,781	107.43	99.05
2011	3	1,081,641	70.74	72.29	3	3,261,346	101.50	102.22
2012	4	1,273,896	66.02	65.24	3	2,091,449	85.18	83.08
2013	2	862,893	87.96	83.91	3	1,997,118	98.85	95.49
2014	1	629,314	64.88	64.88	2	1,643,954	77.18	76.69
Σ	**17**	**7,041,777**	**-**		**27**	**18,318,782**	**-**	
	Average value		**414,222.18**		**Average value**		**678,473.40**	

Source: own calculation. Data for 2014 are valid as of 31 May.

Table 3. Road maintenance assumptions expressed as the percentage of road's area to be reconstructed, if not stated differently.

Year	Bituminous roads				Concrete roads	
	Wearing course replacement	**Complete reconstruct.**	**Partial reconstruct.**	**Evenness improvement**	**Crack sealing *(% of length)***	**Reconstruct.**
Price at year 0	38.91 PLN (0.55 • constr. cost)	95.50 PLN (1.35 • construction cost)		5.12 PLN	37.86 PLN	207.59 PLN (2.1 • constr. cost)
1						
2			1%			
3			1%			
4			2%			
5			3%	3%		
6			4%			
7			5%		2.5% ‡	2.5%
8			10%			
9			±			
10	100%					
11						
12			1%			
13			1%			
14			2%		2.5% ‡	2.5%
15			3%	3%		
16			4%			
17			5%			
18			10%			
19			±			
20	100%					
21					2.5% ‡	2.5%
22			1%			
23			1%			
24			2%			
25			3%	3%		
26			4%			
27			5%			
28			10%		2.5% ‡	2.5%
29			±			
30		100%				100%

Source: (DROCAD Sp. z o.o., 2014).

± *Kalkulator drogowy* proposes additionally a 15% of road's area for partial reconstruction in years 9, 19 and 29, however it seems redundant given full reconstruction in years 10, 20 and 30.

‡ *Kalkulator drogowy* proposes 1% only.

Table 4. NPV calculations for flexible and rigid pavements. All values should be treated as costs.

Year	Bituminous roads			Concrete roads		
	Construction	**Maintenance (nominal)**	**Contribution to NPV**	**Construction**	**Maintenance (nominal)**	**Contribution to NPV**
0	99,036			138,390		
1						
2		1,405	1,161			
3		1,440	1,082			
4		2,952	2,016			
5		4,781	2,969			
6		6,202	3,501			
7		7,946	4,078		9,199	4,720
8		16,290	7,599			
9						
10		69,726	26,882			
11						
12		1,798	573			
13		1,843	534			
14		3,778	995		10,935	2,879
15		6,120	1,465			
16		7,939	1,728			
17		10,172	2,012			
18		20,852	3,750			
19						
20		89,255	13,267			
21					12,998	1,756
22		2,302	283			
23		2,359	263			
24		4,836	491			
25		7,835	723			
26		10,163	853			
27		13,021	993			
28		26,693	1,851		15,450	1,071
29						
30		280,442	16,072		609,593	34,935
	NPV (bituminous): 194,177 PLN ***5.67% higher***			**NPV (concrete): 183,751 PLN**		

Source: own calculation on the basis of the assumptions presented throughout the paper.