ROAD ASSET EVALUATION MODELS

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ABSTRACT

This paper is devoted to the problem of modelling the value of roads. Conducting asset evaluation helps to fulfil legal requirements, ensure appropriate funding of infrastructure and improves management by providing a financial perspective to technical evidences. Addressing evaluation problem requires, however, careful and interdisciplinary approach. It is crucial that road authorities and specialists involved in evaluation process understand nuances of modelling and, more importantly, interpreting the results. In this paper, we provide a discussion of road asset evaluation problem, indicate properties, which an "ideal" evaluation model should met as well as give some guidelines to practitioners. The paper concludes with a discussion of three examples of real-life evaluations conducted in Poland and Germany.

1 VALUE OF ROADS

Road infrastructure is subject to technical evidence but sometimes it is not included into accounting records. Such situation is common in many countries, in particular in Poland and Germany. On the other hand, law regulations require property—including road infrastructure—to be tracked by a financial record. To handle this problem road authorities must create an opening balance by evaluating the financial value of their assets. This is a complex modelling task requiring combination of knowledge and skills in accounting, civil engineering and data analysis. This paper aims at characterizing the properties of an "ideal" road asset evaluation model and analyses three practical approaches to this problem.

To fully understand various aspects of road asset evaluation one should analyse what constitutes the value of a road. This issue can be analysed from different points of view, which are illustrated in Fig. 1.

Consider for example mortgage value. It depends on these elements of property, which retain value for a long time. In case of roads, these would be their bases and surfaces, while the mortgage value of easily torn pavement markings is negligible. Alternatively, one can assess the service value of property i.e. the income it provides to users. For instance, detouring closed road section (e.g. to repair it) results in additional costs of fuel and time spent by drivers and passengers. Evaluation of this costs may help to decide how to repair the section: close one lane at a time and introduce swinging movement or build a temporary road nearby. The latter variant is more expensive for the road authority but might be the cheapest for the whole community. Roads can be also evaluated from other points of view: social, ecological, military etc. Values obtained for each of these categories are different, as they describe different benefits brought by roads.

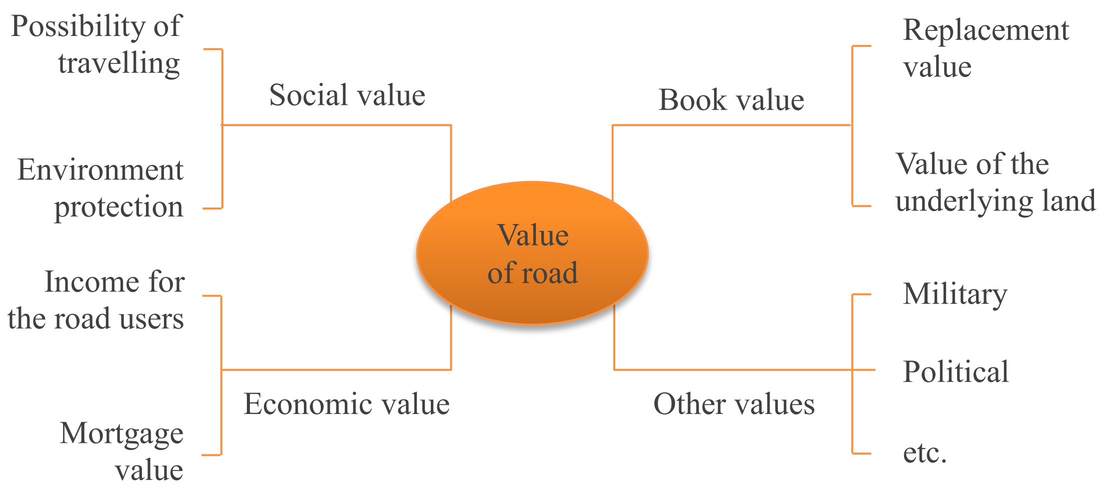

Figure 1: Different perspectives on assessing the value of a road.

Consequently, in the context of asset evaluation specifying its purpose is a matter of key importance, as it determines the possibilities of interpreting and using results (Cymerman and Hopfer 2010). It also influences the choice of evaluation methods and appropriate mathematical model. The latter one seems to be less significant, because discrepancies resulting from correct application of various possible models lead to much lower differences in the final evaluation than the change of approach (e.g. the change from estimating mortgage value to social one).

Evaluating infrastructure has many advantages, whose thorough discussion can be found in a book PIARC (2005). Among the most important benefits one should mention fulfilling legal requirements, determining value of capital accumulated in road network and their depreciation, introducing understandable financial language as well as supporting decision making process by basing them on both economic and technical information. The overall goal of asset management is to incorporate into road authorities efficient, business-oriented management techniques.

2 HOW TO EVALUATE ROADS?

Having made a decision to evaluate road value a natural question arises: how it should be done? The basic rules are usually regulated by law. A summary of regulations applicable in Poland can be found in Cymerman and Hopfer (2010) but the basic notions and methods seem not to vary much between countries. For accounting purposes two types of value are required: initial value (cost) of an asset C and its current value V. The difference between those two describes the total depreciation D of the asset.

$$V = C - D \qquad (1)$$

Evaluation of fixed assets consists either in estimating its market (or fair) value or in calculating the costs of replacing it with a new one, which has comparable technical characteristics. Road infrastructure is not subject to market exchange, therefore in this case the cost approach is used.

Evaluation of replacement cost C of a road in all models discussed in this paper follows the same scheme, summarized in Table 1. First, road is divided into uniform sections $i \in S$, for which all parameters used in evaluation model are constant. Then, for each section one uses equation (2) to calculate its area and equation (3) to obtain unit replacement cost. Finally, replacement cost of the whole road, given by formula (4), is obtained by summing costs of each section. The only problem in this procedure is that the function $f_{C(i)}(\ldots)$ describing unit cost in equation (3) is unknown and must be modelled based on available data. Such modelling is the most important task in asset evaluation, therefore it requires special attention.

Table 1. Outline of model for evaluating replacement cost

Scope		**Estimated values**	**Symbol and unit**	**Model**	
Scope	i^{th} uniform section	1. Area	$A(i)$ [m²]	$A(i) = (length\ of\ i^{th}\ section) \cdot (width\ of\ i^{th}\ section)$	(2)
	i^{th} uniform section	2. Unit cost	$C(i)$ [PLN/m²]	$C(i) = f_{C(i)}(\ldots)$	(3)
	whole road	3. Replacement cost	C [PLN]	$C = \sum_{i \in U} C(i) \cdot A(i)$ where U is a set of uniform sections	(4)

It seems beneficial to enumerate properties, which should be fulfilled by an "ideal" asset evaluation model.

1. Adequacy. The purpose and assumption of evaluation should correspond to the needs addressed by the model and should be documented.
2. Objectivity. Model should be based on sound technical data, measurements, norms etc. Assessment of experts should be the last resort as it requires arbitral decisions, which makes evaluation random and non-repeatable.
3. Interpretability. Ideally all parameters should have clear technical or accounting interpretation. Moreover, the model should be as easy as possible without hindering its explanatory properties.
4. Formality. Ideal model should be mathematically strict and well fitted to the data. Its verification is usually difficult, as it requires testing against new data—in our case against the costs on newly built roads. Nevertheless, it is possible and important to estimate the accuracy of the obtained results.
5. Usability. It is important to choose appropriate aggregation level—for accounting purposes it may be convenient to treat the whole road as a single asset, while performing analyses may require more detailed information. Saarinen (2007) points out that in an ideal model, depreciation should match the need of upkeep and reconstruction and value should reflect the physical conditions.

Usually it is impossible to meet all these requirements due to lack of data, modelling problems or legal requirements. For instance, in Poland depreciation of roads and bridges must be computed at a fixed annual rate of 4.5% independently on the real condition, traffic and wear.

3 ROAD ASSET EVALUATION MODELS

Practical aspects and nuances of road asset evaluation can be illustrated by a comparison of evaluation models. In this section we compare three such models. Except from providing some basic information about purpose and scope of evaluation, the structural equations and diagrams describing models are given. In each diagram, the input and output data is plotted on a grey background, whereas the schematic representation of the core model functions $f_{\ldots}(\ldots)$ is plotted without background.

Calculation of the replacement cost for each presented model follows the same general scheme summarized in Tab. 1, therefore the formulas (2), (3) and (4) are not repeated in the following descriptions. Apart from replacement cost one also needs to determine the initial depreciation and road value, see equation (1). This issue is much more complicated, since assessment of road wear is unavoidably arbitrary. For example, it is not clear what does it mean that a road is fully worn: is it enough that there are potholes? or are cracks or ruts necessary as well? how deep ruts are still acceptable? Lack of clear answer to such questions causes significant differences in monetary values assigned to a given road section by various models. Consequently, comparing the values of roads obtained in different studies is difficult and requires an in-depth examination of evaluation criteria. On the other hand, estimates of the replacement cost of the road should not vary much between models.

3.1 Road and Bridge Research Institute model for Poland

Purpose: gather macroeconomic data and define terminology
Scope: all national, state and district roads in Poland
Data: survey sent to local road authorities

Model presented in Tab. 2, Fig. 2 and Fig. 3 was created by the Road and Bridge Research Institute (Szrajber and Kretkiewicz 2006). It has macroeconomic character, as its scope includes evaluation of all roads in Poland, except for the lowest category of the "last kilometre" access roads.

Table 2. Road and Bridge Research Institute model of road value

		Estimated values	Symbol and unit	Model	
Scope	network administrated by single road authority	1. Area of roads requiring i^{th} treatment	$A(i)$ [m^2]	assessment of local road authorities	
		2. Repair costs (analogue of depreciation)	$R(i)$ [PLN/m^2]	$R(i) = f_{R(i)}(required\ treatements,\ treatment\ costs)$	(5)
		3. Road value	V [PLN]	$V = C - \sum_{i \in T} R(i) \cdot A(i)$ where T is a set of treatments	(6)

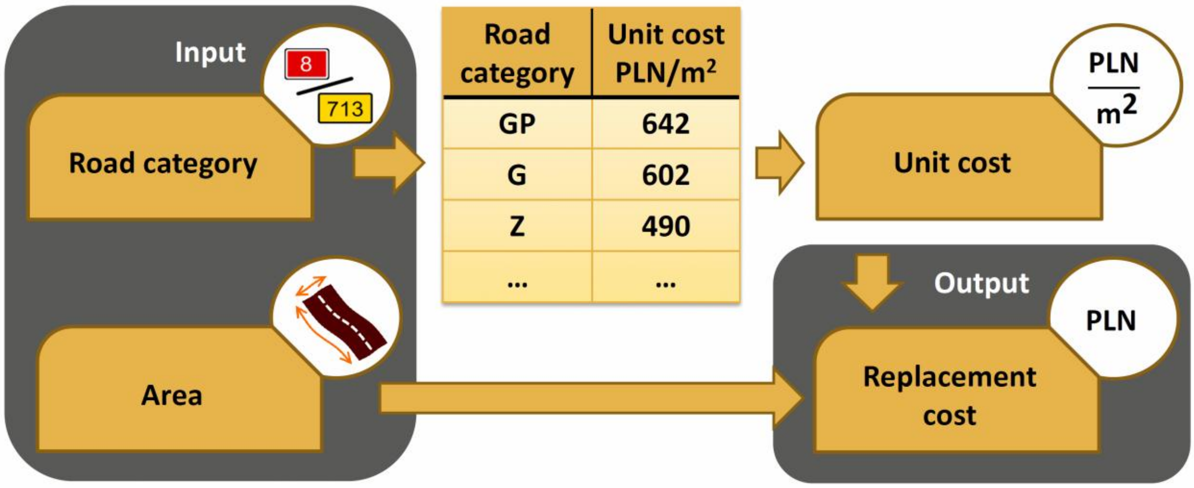

Figure 2: Model of road replacement cost (Road and Bridge Research Institute)

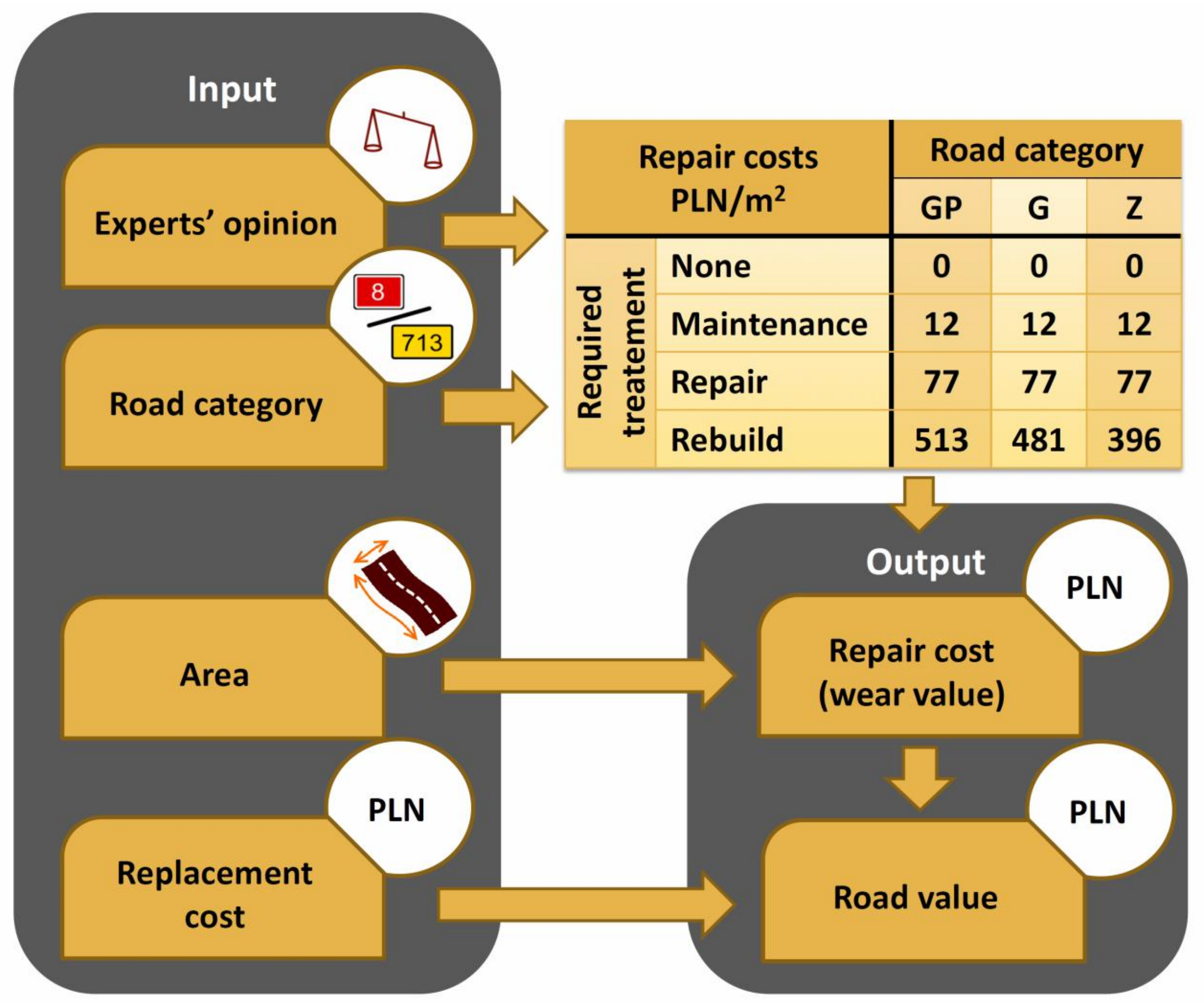

Figure 3: Model of road value (Road and Bridge Research Institute)

Data was acquired in an aggregated form by means of a survey among road authorities. Each of them provided information about total length and area of roads in each category and about total area of roads requiring each of the following treatments: maintenance, repair or rebuild. Szrejber and Kretkiewicz (2006) noticed that assessment of road wear varied a lot between authorities. It is not clear to what extent this variety is due to differences in condition of road networks and to what extent due to severity (or mildness) of different expert's opinions. Initial depreciations and road values are therefore not really comparable between administrative units but are still sufficient for macroeconomic purposes. Determination of the current road value in equation (6) was based on the replacement cost and the cost of treatments required to bring the road back to its initial (unused) condition. This model is very simple due to use of only four well-defined categories of required treatments. However, large differences between costs of these treatments and lack of intermediate categories between them inevitably decreases model's accuracy.

This macroeconomic study provided an estimate of the previously unknown total value of capital invested in road network in Poland and of their present value (as of 2006). The latter sum amounted to 497 billion PLN. This is twice more than the expenditures of the central budget of Poland (223 billion PLN) and nearly a half of its GDP (1058 billion PLN). Keeping so expensive property in satisfactory condition is hence very important, as insufficient funding or ineffective planning of treatments results in loses counted in billions.

3.2 HELLER Engineering model for Saarland

Purpose: introduce double-entry accounting
Scope: state roads in German state of Saarland
Data: area, class and condition of roads (ZEB)

HELLER Engineering and PwC proposed an asset evaluation model, described in Tab. 3, Fig. 4 and Fig. 5, for road authority in Saarland, which is one of the sixteen states in Germany (Düsterhöft 2008). This evaluation concerned *Landesstraßen* i.e. state roads—a road category less significant than federal roads but more important than district road. Replacement costs were based on structure classes (*Bauklasse*) describing the structure and hence durability of a uniform road section.

Table 3. HELLER Engineering model of road value

Scope		Estimated values	Symbol and unit	Model	
Scope	i^{th} uniform section	1. Cost of surface and cost of base	$C_S(i), C_B(i)$ [EUR]	$C_S(i) = 0.2 \cdot C(i)$ $C_B(i) = 0.8 \cdot C(i)$	(7)
		2. Surface depreciation	$D_S(i)$ [EUR]	$D_S(i) = f_{D_S(i)}(road\ condition\ \ ZEB)$	(8)
		3. Base depreciation	$D_B(i)$ [EUR]	$D_B(i) = f_{D_S(i)}(base\ age)$	(9)
	whole road	4. Surface value	V_S [EUR]	$V_S = \sum_{i \in U} (C_S(i) - D_S(i)) \cdot A(i)$ where U is a set of uniform sections	(10)
		5. Base value	V_B [EUR]	$V_B = \sum_{i \in U} (C_B(i) - D_B(i)) \cdot A(i)$ where U is a set of uniform sections	(11)

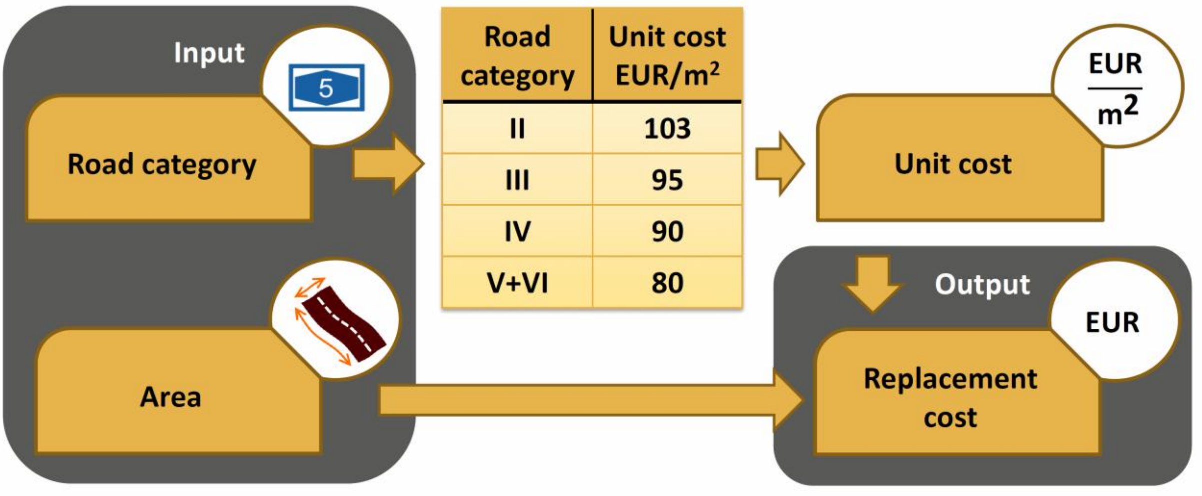

Figure 4: Model of road replacement cost (HELLER Engineering)

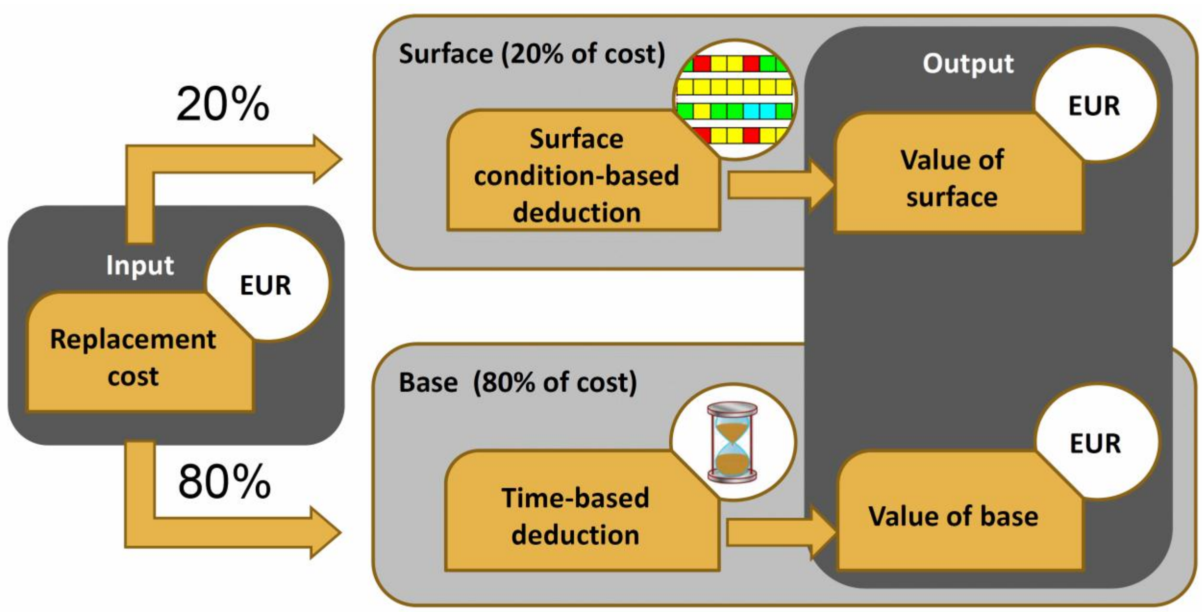

Figure 5: Model of road value (HELLER Engineering)

This model implements an idea of separating the value of surface and base of a road, see formula (7). Such measures were taken to introduce a clear division between operating expenditures (OPEX) associated with surface maintenance and capital expenditures (CAPEX) associated with base maintenance. This division introduced for accounting purposes coincides with different ways of assessing wear and tear. Depreciation of surface was based on road condition evaluation performed according to ZEB standard, while base was assumed to depreciate 1.8% each year. This means that the durability of base is taken to be 55 years.

3.3 HELLER Consult model for Silesian Voivodeship

Purpose: introduce existing roads into accounting system and facilitate management
Scope: state roads in Silesia Voivodeship in Poland
Data: area and structure of roads and their bearing capacities

HELLER Consult performed a pilot evaluation project of a road network of 1200 km of state roads (*drogi wojewódzkie*), which are less important than national roads but more important than district ones in the Silesian Voivodeship (*województwo śląskie*), one of 16 provinces in Poland (Opara et alia 2011). Except for fulfilling legal requirements of an appropriate accounting, this model is meant to provide information facilitating management of roads. For this reason is was especially important to ensure its objectivity and reliability. The model is entirely based on legal regulations, norms and technical catalogues. The unit replacement cost of each uniform section was determined out of the road structure and then processed through a regression model. Fig. 6 provides a visualization of algorithm for obtaining the value of model in equation (3).

Formal mathematical formulation of model gives possibilities for better interpretation and sensitivity analysis. For instance, in the simplest approach information about road structure was aggregated into one parameter called standard (substitute) thickness H_c [cm], which was introduced by GDDP (2001) to facilitate overlay design. Unit replacement costs in equation (3) can be estimated as a linear model:

$$C(i) = 11.9 \cdot H_c + 65.0 \qquad (12)$$

This means that unit increase in road's substitute thickness increases the unit replacement cost by $\partial C(i)/\partial H_c = 11.9 \approx 12$ [PLN/m^2]. Opara et alia (2011) notice, that introducing more complicated regression models than (12) e.g. by aggregating road structure into two parameters depending on function or material of each layer improves accuracy of results.

Formal mathematical structure of HELLER Consult model allowed for determining its accuracy. The maximal estimation error of the replacement cost was 33%. To improve it, one needs primarily to provide better data on costs of construction and treatments and more accurate evidence of roads. Taking into account the complexity and variety of road structures, as well as accuracy of the state-of-the-art road measuring techniques, reaching errors lower than 10-15% seems very difficult, if not impossible.

Table 4. HELLER Consult model of road value

		Estimated values	Symbol and unit	Model	
Scope	i^{th} uniform section	1. Unit cost of a new section equally durable as the i^{th} section	$C_D(i)$ [PLN/m^2]	$U(i) = f_{C_D(i)}(load\text{-}bearing\ capacity,\ cost\ assesment\ of\ new\ roads)$	(13)
	whole road	2. Road value	V [PLN]	$V = \min\left(C, \sum_{i \in U} C_D(i) \cdot A(i)\right)$ where U is a set of uniform sections	(14)
		3. Depreciation	D [PLN]	$D = C - V$	(15)

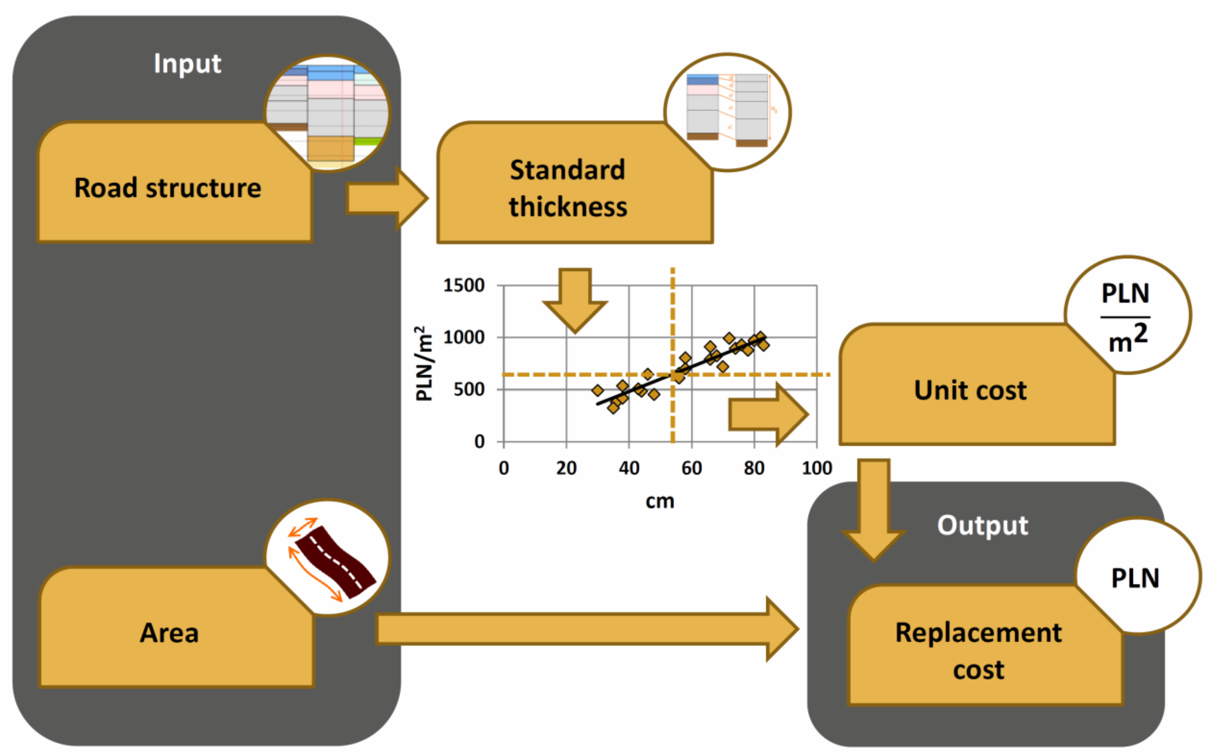

Figure 6: Model of road replacement cost (HELLER Consult)

Replacement costs were evaluated with use of standardized thickness of structure. This measure corresponds with the durability (or bearing capacity) of a road understood as the number of axles weighting 100 kN each, which can be carried by the road within its lifetime. Consequently, evaluation of road value was also based on its durability, which was measured with use of a falling weight deflectometer (FWD) and some non-linear processing depicted in Fig. 7. This approach gives a technical interpretation of the accounting term of depreciation calculated with formula (15). It may be thought of as a difference between the value of a road having the design (full, initial) bearing capacity and a new one, whose durability is equal to the durability of the existing road.

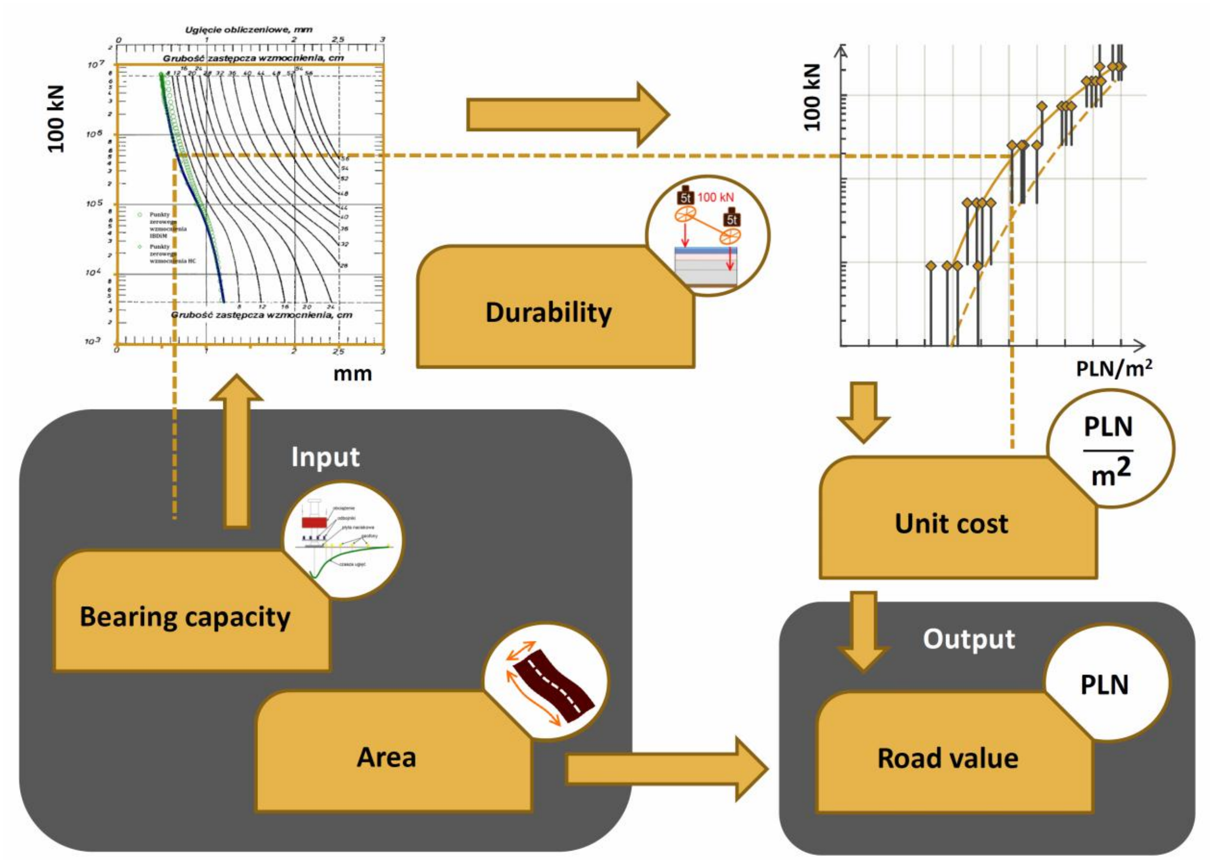

Figure 7: Model of road value (HELLER Consult)

4 SUMMARY

All of the described models were created according to already available or specially collected road data and applied in practice. Each of them has both advantages and drawbacks described in previous sections and summarized in Tab. 5. Overall all of them fulfilled their purposes. The main differences between these models lies in the quality of input data and the extend of formal analysis.

The necessity of conducting asset evaluation seems to be commonly recognized nowadays. Addressing this problem requires, however, careful, interdisciplinary approach. It is crucial that road authorities as well as and specialists involved in evaluation process understand nuances of modelling and, more importantly, interpreting the results. An “ideal” model should be adequate—address appropriate purpose, objective—based on sound technical data, well-interpretable, mathematically strict and tailored to the needs of the road authority.

Table 5. Overall comparison of the three models

	Road and Bridge Research Institute	**HELLER Engineering**	**HELLER Consult**
Adequacy purpose and kind of value	+ macroeconomic	+ accounting	+ accounting
Objectivity reproducibility, comparisons	− poor input data	+ good	+ good
Interpretability easiness to understand	+ simple model	+ advanced model	+/− complex model
Formality sensitivity, accuracy etc.	− coarse, inaccurate model	+/− no accuracy analysis	+ formally analysed
Usability easiness to implement, significance for management	+ state-wide view on the road network	+ surface – CAPEX base – OPEX	+ legally appropriate

Implementation of a road asset management system gives an opportunity to act in a more informed and hence more effective way. It also contributes to better understanding of road management issues by the public and decision makers, which is crucial for ensuring financing level sufficient to protect huge capital invested into road infrastructure against excessive wear.

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