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Technicko-ekonomický software Buildpass pro údržbu a obnovu objektů

Technical-economic software Buildpass for properties renovation and maintenance

Summary

Maintenance and renewal costs for structural objects are a significant part of costs in the life-cycle of structures. Rational owners and construction service engineers try to minimize outlays on maintenance and renewal. However, at the same time it is necessary to respect a certain standard in the condition of a construction, to keep it above a fixed limit given from the type and demands on usage of the existing structural object.

On the market there exist various instruments from the field of facility management, which deal with the problems of maintenance plan setting and structural objects renewal. Software processing and connection to graphic systems is usually very beneficial. The weak aspect of these systems is of course an insufficiently worked-out model of maintenance and renewal, which would realistically describe the ageing of a structural object at the level of individual construction components. From these there follow inaccurate outputs on the level of the technical and economic formations which serve as a basis for user decision-making as to how to further dispose of the structural object.

The aim of the publication is to describe the modelling and optimisation of renewal costs at the level of structural elements. The topic is part of a theory for modelling of LCC constructions. LCC behaviour with individual elements can be captured by a system of periodically repeated renovation matrices. However, every construction which consists of various structural elements brings certain correlations among elements which involve the mutual influence of individual renovation matrices namely within the context of an economical disbursement of financial means on a construction in its entirety.

For the LCC rationale it is necessary to establish the mathematical correlations, which will create a basis for the searching for, and modelling of, a solution for the minimization of costs issued by an administrator (or owner) of a construction.

Souhrn

Náklady na údržbu a obnovu objektů jsou významnou součástí nákladů životního cyklu staveb. Majitelé a správci objektů se snaží prostředky vydávané na údržbu a obnovu minimalizovat. Zároveň je však potřeba respektovat požadovaný standard stavu objektu, jenž je potřeba udržovat nad uživatelem stanovenou minimální hranicí, která je dána typem a nároky na užívání daného objektu.

Na trhu existují nástroje z oblasti facility managementu, které se problematikou stanovení plánu údržby a obnovy objektů zabývají. Softwarové zpracování a propojení na grafické informační systémy je obvykle na vysoké úrovni. Slabinou uváděných SW systémů ovšem je nedostatečně propracovaný model údržby a obnovy, který by měl reálně popisovat stárnutí objektu na úrovni jednotlivých konstrukčních prvků. Z toho plynou nepřesné výstupy na úrovni technických i ekonomických sestav, jež slouží jako podklad pro uživatelské rozhodování jak s objektem dále nakládat.

Cílem publikace je popsat modelování a optimalizaci nákladů obnovy na úrovni konstrukčních prvků. Téma je součástí teorie a modelování LCC objektů. Chování LCC u jednotlivých prvků lze zachytit systémem periodicky se opakujících matic obnovy. Ovšem každý objekt, který se sestává z různých konstrukčních prvků přináší určité souvztažnosti mezi prvky, které přinášejí vzájemné ovlivnění jednotlivých matic obnovy a to v kontextu hospodárného vynakládání finančních prostředků na objekt jako celek.

Pro racionalizaci LCC je potřeba stanovit matematické souvztažnosti, které vytvoří základ pro modelování a hledání řešení pro minimalizaci nákladů vydávaných správcem (resp. majitelem) objektu.

Klíčová slova:
údržba, obnova, LCC, životní cyklus, technická vazba, ekonomická vazba, matice obnovy, konstrukční prvek, životnost, krok obnovy, délka kroku obnovy, výška kroku obnovy, toleranční pásmo, periodicita, úspora

Keywords:
maintenance, renovation, LCC, living cycle, technical linkage, economical linkage, renovation matrix, structural element, lifetime, renovation step, length of renovation step, height of renovation step, toleration zone, periodicity, saving

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1. Life Cycle Costs of Structural Elements

The analysis of life cycle costs of a building (Life Cycle Costs, LCC),which is described by Čápová in [3] and [5], is focused on the empirical improvement of costs during an entire lifetime. The lifetime of the construction is limited not only by its technical but also its economic lifetime. With the technical lifetime the emphasis is put on material characteristics of a construction and the lifetime of the construction, which is dependent especially on the provision of building elements with a long-term viability. It concerns those structures of the construction which have, from the viewpoint of the technical lifetime, principal significance because with their damage (loss of performance of their function) the construction is not functional, threatens to collapse and any repairs become technically and economically extremely demanding.

From the viewpoint of the cost level for repairs it is more effective to remove the construction and build a new one. In the case of the economic lifetime this concerns the period in which it is appropriate to use the building economically. It is usually shorter than the technical. Very often it concerns the loss of economic usefulness which can be connected with the permanent loss of net income with reference to disproportionately high costs and it would seem preferable to remove the building and replace it by a new building and thus re-evaluate the land. The decision making methods are stated by Beran in [1].

The resulting LCC calculation of the relevant inputs which concern the technical parameters of structural elements and the time period for incurring costs related to them should be an important basis for the decision of an investor, a designer and any future user in choosing an optimum variant of a technical solution for a construction and also looking to ecological aspects and long-term economic consequences. Costs connected with the implementation, use and disposal of a building are divided by Čápová and Kremlová in [4] into 3 basic groups:

1) Costs directly related with the technical parameters of a construction– investment costs, repair and maintenance of a building costs, reconstruction costs, costs relating to modernization and disposal of a building,
2) Operating costs of a building – energy, cleaning, depreciation etc.,
3) Administrative costs related to property management – taxes, insurance, administration of a building etc.

Consequently, on the basis of the stated overview it is possible to establish a basic relation for setting up the life cycle costs of a building (LCC) as stated by Čápová and Kremlová in [3] as

$$LCC = \sum_{n=0}^{t_D} \frac{C_n}{(1+i)^n} \tag{1}$$

where C_n is the cost in the year *n*,

i is the discount rate (time value of money) and
t_D is the length of the reported period (lifetime of a building).

The set of problems is focused on costs related to the technical parameters of a construction. Life cycle costs can be simply written also as the sum of the above mentioned groupings of costs:

$$LCC = C_T + C_P + C_A \tag{2}$$

where LCC Life Cycle Costs,
C_T costs related to the technical parameters of a building,
C_P operating costs and
C_A administrative costs.

Costs related to the technical parameters of a building (CT) can be written by the following relation:

$$C_T = \sum_{n=0}^{t} \frac{\sum_{j=0}^{p} C_{T_j}}{(1+i)^n} \tag{3}$$

where T_j height of j-th category of costs related to the technical parameters of a building,
n year of evaluation,
t length of the life cycle of a building (lifetime),
p number of categories of costs related to technical parameters of a building,
i discount rate.

From the viewpoint of the time classification of a LCC construction, the costs can be divided as follows.

1) In the investment phase (implementation) this concerns the investment costs (purchase price).

2) In the operating phase these are the costs for:

- repair and maintenance of a building,
- modernization,
- reconstruction.

3) In the liquidation phase this concerns the costs of ecological disposal of a building.

2. Life Cycle of Structural Elements

A life cycle of a element expresses in what time cycle and with what costs it will be necessary to carry out the renovation of an appropriate structural element so that the standard of use is retained and at the same time, that it is not renovated unnecessarily early, when there has not yet been exhausted its use potential. Curves for the wear and tear of structural elements are stated by the authors in [6], [10] and [11].

The first approach is the description of this cycle by the length of the step and to consider that after its expiry the structural element will be completely restored. Giving a more precise principle which better describes the real behaviour and lifetime of structural elements is a system based on the description of a life cycle of a element with the help of a matrix. This matrix expresses the description of the lifetime of a element in such a way that it solves the problem of the description of cycles, where there is not any periodicity of one step for the recommended renovation of elements. The result is that the appropriate matrix represents one periodical step which can be described by any non-periodical cycle.

Variability is not enabled only in the lengths of individual non-periodical cycles but also in their heights. The height is understood as a percentage of costs which must be spent on a given renovation of a element.

As an example there can be given air conditioning where renovation takes place after 15 years but regularly the renovation cost is rotated to the extent of ¼ of elements and completely for the whole system. In this case there is introduced in the renovation matrix a step of 15 years length with the height of 25 % and a second step with the same length but with the height of 100 %, as is shown in Figure 1.

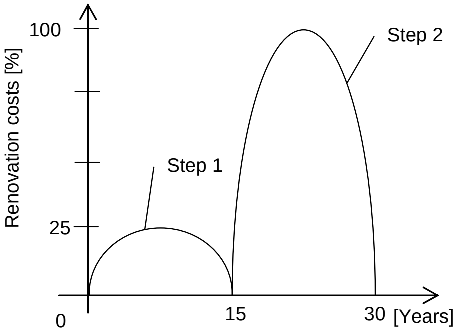

Figure 1. Example of a scheme of renovation matrix

In the course of the calculation the lifetime matrix cyclically repeats and will create a course for the structural element renovation which is shown in Figure 2.

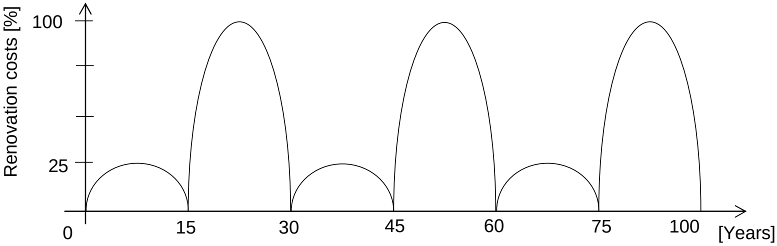

Figure 2. Scheme of the renovation element expressed by the periodicity of the renovation matrix

3. The principle of designing LCC of structural elements of a building construction

The basic principle of the model pre-set for optimizing steps is establishing linkages among structural elements and determining their behaviour. The linkages can be divided into two groups:

- economic,
- technical.

The economic linkage means cost saving in carrying out the renovation of two or more structural elements simultaneously against the sum of costs spent for the renovation of the same structural elements without mutual time coordination. The savings can be for technical reasons, when for example we use the built scaffolding for the façade renovation and at the same time we carry out the renovation of tinsmith elements. Another reason can be an organizational one when, e.g. during the renovation of a rising main we undertake a part of the painting and facing, as even this can be considered the carrying out of the complete renovation of painting or facing for the whole construction. An economic linkage is discerned by the fact that the use of the linkage is directed by further conditions (which will be stated further on in this chapter)

The technical linkage means a strong connection of the renovation of one structural element with another one, while the linkage is, contrary to the economic linkage, always applied. An example can be the change of roof timbers, when we automatically renovate roof insulation and roof cover. Similar to the economic linkage, the technical linkage also brings total cost savings.

Further parameters of optimization are tolerance limits for deviation from the optimum cycle for structural parts as independent elements. In practice it indicates how much it is possible to prolong or to shorten the length of the renovation step with regard to a worse condition of the structural element possibly involving its pointless preliminary change. In general it can be said that with the majority of structural elements the tolerance deviation moves on the level 20% of the length of one step of the renovation as stated by Seeley in [14]. For the given reasons there follows also a recommendation for instigating economic linkages only in cases when we get from them a minimum 5% savings on total costs of the renovation.

In given types of linkages the elements divide into two groups. *Influencing* and *influenced* elements. When defining the linkages it is unanimously determined which of the elements is influenced and which is influencing. The influencing element is not affected by the influenced element, therefore its renovation cycles behave independently of it. The influenced element monitors cycles of the influencing element and according to the type of the linkage and further parameters its cycles of renovation are directly affected by the influencing element.

It is valid that one element can be for a group of elements the *influencing* element, and at the same time for another group of elements it can be an *influenced* element. To prevent the cycling of the system of linkages, the elements will be divided into layers where there is valid a rule that the *influenced* element connects to the *influencing* element which is at a minimum one hierarchical layer higher. Schematically it is shown in Figure 3.

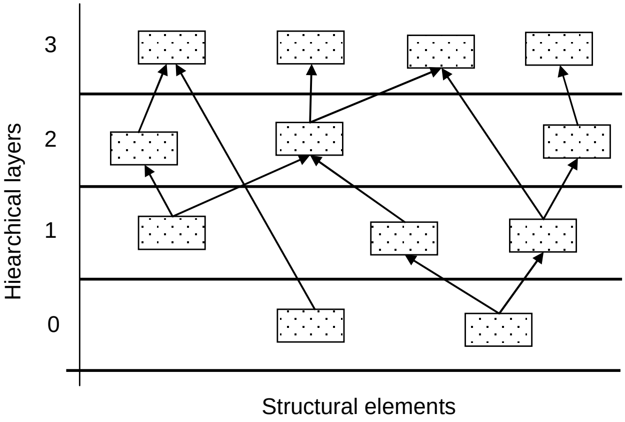

Figure 3. Scheme of the description of linkages among elements

As has been stated before, technical linkages are always applied. It means that the algorithm solves in the case of an affected element whether there would be in the area of the linkage any prolongation or shortening of the length of the renovation step (in an ideal case the renovation cycles of both elements can transect without further changes). In the following Figure there is seen a scheme of cycles of two elements, which are not bound by any linkage and each behaves according to its own renovation cycle.

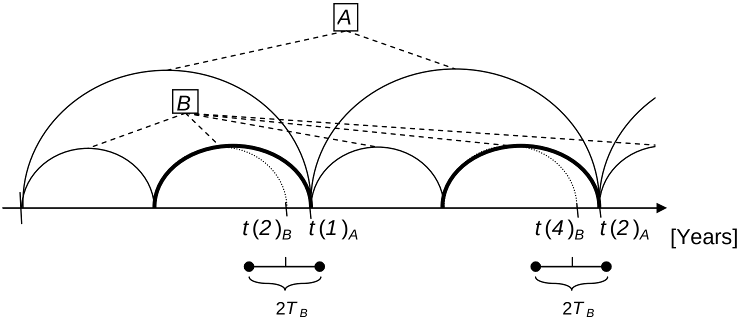

Figure 4. Scheme of renovation cycles of elements without a linkage

At the moment of the introduction of a technical linkage between an influenced element *B* and an influencing element *A* an algorithm solves whether there can be a final closed renovation step of the element *B* from points $t(2)_B$ and $t(4)_B$ prolonged to points $t(1)_A$ and $t(2)_A$, which is a planned renovation of the influencing element or whether the following renovation cycle will be shortened. The value of a maximum possible prolongation of a cycle T_B with the element *B* decides any possible prolongation.

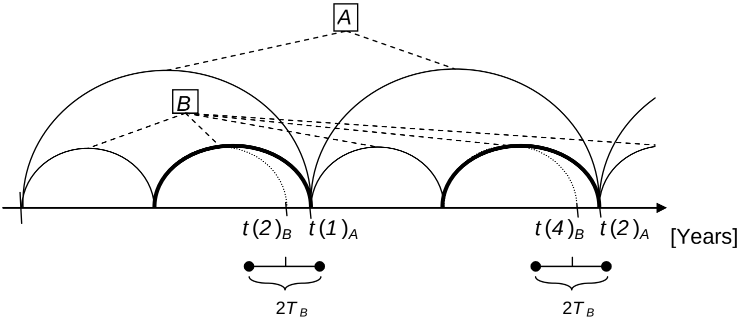

Figure 5. Prolongation of the cycle length in *technical/economic linkage*

Figure 5 shows the case where it is possible to prolong the cycle. Points $t(1)_A$ and $t(2)_A$ fall within the zone of the possible prolongation of the length renovation cycle $t(2)_B$ and $t(4)_B$ and the original cycle is prolonged. In the figure it is depicted in bold.

$$t(n)_B = t(m)_A \quad \text{if} \quad t(m)_A - t(n)_B < T_B \quad n, m \in N \tag{4}$$

where A influencing element,
B influenced element,
n serial number of the cycle of the element *B*,
m serial number of the cycle of the element *A*,
$t(m)_A$ year of renovation of the element *A* in the cycle *m*,

$t(n)_B$ year of renovation of the element B in the cycle n,

T_B tolerance zone of the possible deviation of the renovation cycle of the element B.

The formula (4) defines the shift of the original planned n th cycle of renovation t(n)B, of the influenced element to the point t(m)A, given by m th cycle of the influencing element provided that point t(m)A occurs in a tolerance zone of a possible change of the cycle defined by the value TB.

In the case that it is not possible to prolong the cycle, then the following cycle, in its technical linkage automatically shortens to the point of the linkage and no further conditions are explored.. The example is seen in Figure 6. The originally planned cycle t(3)B will be shortened to the point t(1)A.

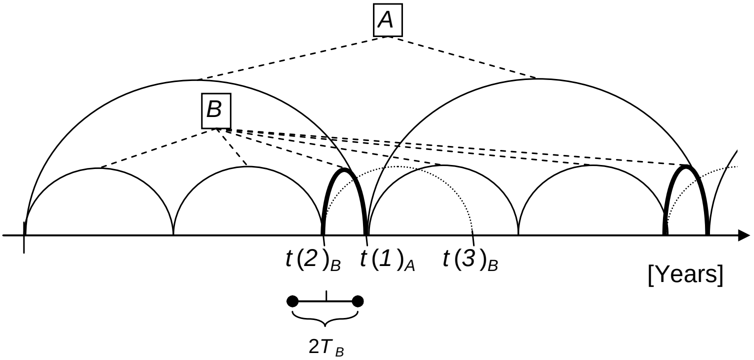

Figure 6. Shortening of the length cycle in *technical linkage*

$$t(n+1)_B = t(m)_A \quad \text{if} \quad t(m)_A - t(n)_B > T_B \ \text{a} \ t(n+1)_B > t(m)_A, \qquad n, m \in N \tag{5}$$

where A influencing element,

B influenced element,

n serial number of the cycle of the element B,

m serial number of the cycle of the element A

$t(m)_A$ year of renovation of the element A in the cycle m,

$t(n)_B$ year of renovation of the element B in the cycle n,

$t(n+1)_B$ year of renovation of the element B in the cycle $n+1$,

T_B tolerance zone of the possible deviation of the renovation cycle of the element B.

The formula (5) expresses the shortening of the renovation cycle of the element B bound by the technical linkage to the element A. If the n-th cycle of planned renovation of the element B is the last cycle of the renovation before the m-th point of a possible linkage $t(m)_A$ and it is not possible to prolong it due to the small extent of the possible prolongation of the cycle T_B, the following cycle of the renewal is shortened from the point $t(n+1)_B$ to the point $t(m)_A$.

Economic linkages contrary to the technical ones are applied only in the case that the linkages among elements can be implemented in the tolerance zone of the influenced element. It means that in the case of the possible prolongation of the length of the cycle the linkage behaves the same as in the technical linkage (see Figure 5). In the situation where there is solved the shortening of the cycle of renovation in the influenced element it is contrary to the technical linkage investigated if the possible shortening is found in the tolerance zone and the linkage is implemented or not. The shortening of the cycle is seen in Figure 7. The planned renovation of the element *B* in the point $t(2)_B$ is shortened to point $t(1)_A$, where there is implemented the economic linkage to the influencing element. Element B behaves similarly in the point $t(4)_B$.

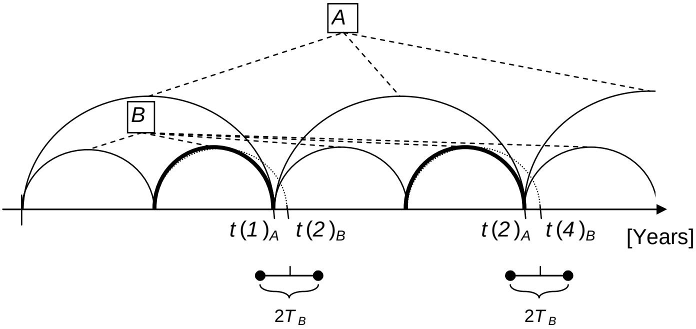

Figure 7. Shortening of the cycle length in *economic linkage*

$$t(n)_B = t(m)_A \quad \text{if} \quad t(n)_B - t(m)_A < T_B \qquad n, m \in N \tag{6}$$

where A influencing element,
B influenced element,
n serial number of the cycle of the element B,
m serial number of the cycle of the element A,
$t(m)_A$ year of renovation of the element A in the cycle m,
$t(n)_B$ year of renovation of the element B in the cycle n,
T_B tolerance zone of the possible deviation of the renovation cycle of the element B.

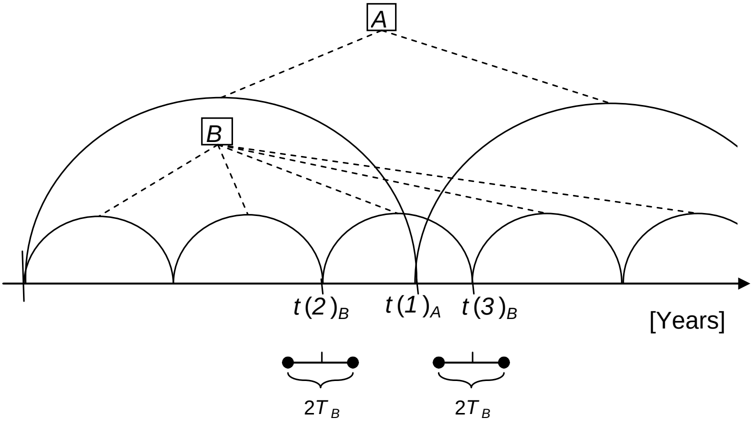

Figure 8. Non-implemented shortening of the length of the cycle in *economic linkage*

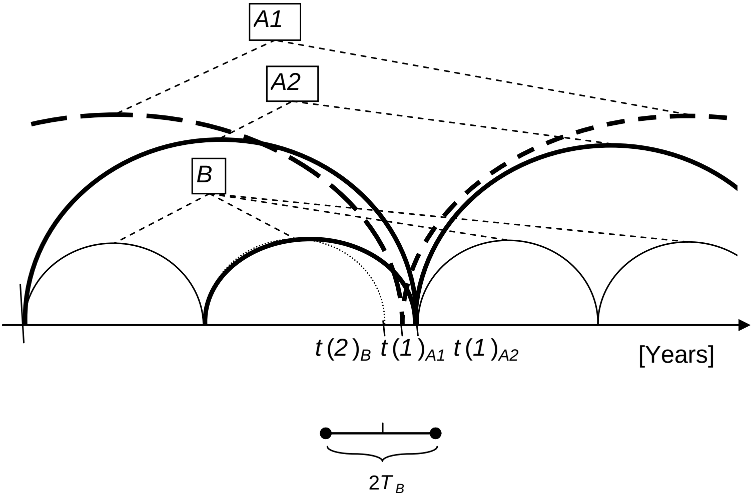

Figure 9. Priority of the *technical linkage* over the *economic linkage*

Formula (6) describes the shift of the original n-th planned renovation cycle $t(n)_B$ of the influenced element in the point $t(m)_A$ given by the m-th cycle of the influencing element provided that point $t(m)_A$ occurs in the tolerance zone of a possible change of the cycle defined by the value T_B.

Figure 8 to the contrary depicts the situation where the linkage among the elements will not take place because the point of the possible economic linkage $t(1)_A$

does not fall into the tolerance zone nor one from the neighbouring cycles of renovation of the influenced element $t(2)_B$ and $t(3)_B$.

In the case that the element is bound by more linkages, the technical link always has priority. The technical linkage is automatically implemented and only after the economic linkage application is tested. The example where thanks to the technical linkage there is not implemented the economic linkage is shown in Figure 9, where between the influenced element *B* and the influencing element *A2* there is a technical linkage and between the influenced element *B* and the influencing element *A1* there is an economic linkage. At the point $t(1)_{A1}$ there is offered an economic linkage to the element *A1*, but priority will be given to the technical linkage in the point $t(1)_{A2}$ with the element *A2*.

If the influenced element is bound by more economic linkages at the same time and during the solution of the shortening or the prolongation of its length of the renovation cycle, there occurs in the tolerance zone the offer of more possibilities of the implementation of economic linkages with influencing elements, then there is chosen such a linkage which will deviate from the original planned term of the renovation for the smallest value and it does not matter whether it concerns the shortening or prolonging of the renovation cycle. The example is in the scheme in Figure 10, where the influenced element is bound by the economic linkage to the elements *A1* and *A2* simultaneously.

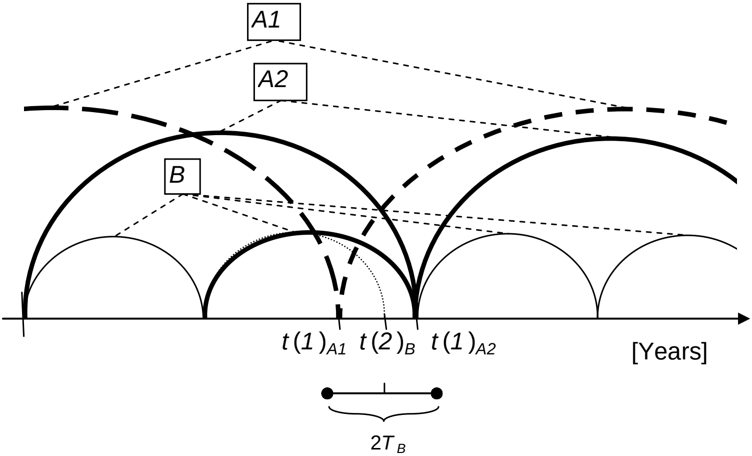

Figure 10. Choice between two *economic linkages*

The result is that there was preferred the linkage in the point $t(1)_{A2}$ to the element *A2*, because the point $t(1)_{A2}$ is closer to the original renovation cycle $t(2)_B$ than the possible economic linkage of the element *A1* in the point $t(1)_{A1}$.

$$t(n)_B = t(m)_A \quad \text{if} \quad \min|t(n)_B - t(m)_A| < T_B \qquad n, m \in N, \tag{7}$$

minimum over all influencing elements A of the element B with the economic linkage.

where A influencing element,
B influenced element,
n serial number of the cycle of the element B,
m serial number of the cycle of the element A,
$t(m)_A$ year of renovation of the element A in the cycle m,
$t(n)_B$ year of renovation of the element B in the cycle n,
T_B tolerance zone of the possible deviation of the renovation cycle of the element B.

Formula (7) defines the choice of the linkage among more possible economic linkages, when the point $t(n)_B$ of n-th planned renovation of the influenced element B is shifted to the m-th point $t(m)_A$ of the influencing element A, which has the smallest absolute deviation from the original plan of renovation and at the same time it falls into the tolerance zone defined by the value T_B.

4. Conclusion

The set of problems in renovation cycles does not have a uniform approach in the literature. The work summarizes and adds information about renovation cycles on the basis of knowledge in the current literature and experience gained by associates, who have been for many years dealing with the practical implementation of renovation of building constructions. The work introduces the concepts of tolerance zone, the volatility of the renovation length, the length and step of renovation and the renovation matrix. From these definitions there is put together a system describing the behaviour of cycles of renovation of structural elements.

In the field of the mathematical optimization of a model the work introduces the concepts of economic and technical linkages among structural elements. Following on from the mentioned linkages there is introduced a summary of mathematical rules for the rationalization for the design of renovation cycles at the level of individual structural elements within the context of a construction in its entirety.

The rational designing of renovation cycles is not determined just for calculations on already existing constructions, but especially it should be used already at the stage of project preparation when these data have a significant influence on the choice of a project variant with regard to LCC.

The given theoretical relationships and dependencies are inbuilt in SW application Buildpass, which is intended especially for owners (administrators) of the building constructions. The tool is focused on professionally qualified planning of the renovation and maintenance of constructions. The solution of a project is based on reference databases of constructions and structural elements, which will enable the gaining of fast results also for users who are not specialists in this field. On the other hand, the tools allow for going into details and to modify designated models on their own merit. The user himself will choose which area to apply and into what depth of detail he himself will engage in the processing of data.

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Curriculum Vitae

Jméno Ing. Daniel Macek, Ph.D.

Vzdělání

1999 - 2003 České vysoké učení technické v Praze, Fakulta stavební
Doktorské studium, disertační práce: „Podpora rozhodování při řízení ekono
1993 - 1999 České vysoké učení technické v Praze, Fakulta stavební
Obor : Podnikání a řízení ve stavebnictví – Inženýrské studium

Odborná praxe

2007 – nyní České vysoké učení technické v Praze, Fakulta stavební
Katedra ekonomiky a řízení ve stavebnictví
Pozice: Odborný asistent
2003 – nyní České vysoké učení technické v Praze, Fakulta stavební
Výpočetní a informační centrum
Pozice: programátor (2003-nyní), vědecký pracovník, odborný asistent (2005-2007), správce mzdového a personálního systému na FSv (2008-nyní)
2000 - 2003 České vysoké učení technické v Praze, Fakulta stavební
Katedra ekonomiky a řízení ve stavebnictví
Pozice: Asistent

Členství v odborných organizacích

Společnost pro projektové řízení
Česká stavební společnost – ČS VTS

Oblasti výzkumných zájmů

Obnova a údržba objektů (Buildpass)
Modelování technicko-ekonomických procesů a simulační metody
Rizika a rozhodovací procesy pro vyhodnocení variant

Výzkumné projekty (spoluřešitel)

COST OC A17.001 – Evropská spolupráce ve vědě a výzkumu, Malé a střední podniky, hospodářský rozvoj a regionální konvergence v Evropě, 2004-2005
MSM 6840770006 – Management udržitelného rozvoje životního cyklu staveb, stavebních podniků a území, 2005-2010.
CIDEAS - Centrum integrovaného navrhování progresivních stavebních konstrukcí, projekt 1M0579 MŠMT ČR, 2007-2011.
JPD3 – Vzdělávání metodiků veřejné správy a profesních organizací při pořizování, správě a obnově veřejného majetku, reg. č. CZ.04.3.07, 2007.

Uplatněné metodiky

Metodická pomůcka posouzení výhodnosti a rizik v životním cyklu svodidel u dálničních staveb vč. postavení na trhu.

Metodické pomůcky ocenění navrhovaných mostních konstrukcí realizovaných v rámci dálničních staveb.

Metodická příručka aplikace propočtů navrhování mostních staveb pro příkaz GŘ.

Pedagogická činnost

Fakulta stavební, ČVUT v Praze
Modelování v řízení (1999-2003)
Projekt z přípravy a řízení staveb (1999-2003, 2007)
Tabulkové procesory 2 (2005-2009) – zavedení nového předmětu
Fakulta stavební, VŠB-TU Ostrava
Matematické modelování ve stavebnictví (2008-2009)
Správa majetku a provoz budov (2008-2009)
Fakulta podnikohospodářská, VŠE v Praze
Facility management a PPP (2008-2009)
Fakulta ekonomická, JU v Českých Budějovicích
Projektování investic (2009)

Publikační činnost

Autor/spoluautor 1 zahraniční monografie, 1 kapitole v zahraniční monografii, 5-ti českých monografií, 6-ti kapitol v českých monografiích, 4 příspěvků v recenzovaných zahraničních časopisech, 2 příspěvků v českých odborných časopisech, 8-mi příspěvků na mezinárodních konferencích ve sbornících, 8-mi příspěvků na českých konferencích ve sbornících a 10-ti dalších publikací.