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Construction time-cost model in Croatia

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SUMMARY

The paper deals with the applicability of the time-cost model for calculating the sustainable construction time for building projects in Croatia. In this model the time is expressed as a function of money in the project, while the specific constants K and B need to be determined. These constants depend on economic characteristics of the country or a larger area, therefore had to be separately calculated for a region with similar economic characteristics. The modelling of the constants was performed for two groups of building projects - the roads and residential and office multi-storey buildings. The obtained results have been analyzed and compared to the corresponding results from abroad.

***Key words**: construction time, time-cost model, constants K and B, linear regression analysis, building projects.*

1. INTRODUCTION

Determining a sustainable construction time is one of the most demanding tasks of managing the building projects. When defining the mutual relationship, all the building participants almost exclusively focus on the cost of construction while the matter of its duration is unjustifiably neglected. Therefore, the deadline is often overscheduled or changed and sometimes even a matter of dispute among the parties to a contract because the overrunning deadline often results in cost increase which has to be covered by a participant of the building process.

Numerous researches, conducted both world-wide and in Croatia, point out the frequency and the damaging effect of being overscheduled with the start date of the project finalization [1-4]. The research conducted by the World Bank or the Standish Group shows that the proportions of the overrun are large and frequent. The research conducted in Croatia [3], shows that about 2/3 of the building projects have significant or large overrun of the initially planned time. The similar results have been obtained in Slovenia [2], as well as in other countries of the broader region. The correlation between the planned and the effectuated fits into the assessment of the Standish Group study which says that only about 1/3 encounters no serious problems in realization of the planned goals of the project in which process 2/3 of the projects do encounter them, so that the researches declared time to be the "killing factor" [4]. It is crystal-clear that the deadline problems transfer to relations among the participants of the project and, eventually, to the financial part of that business.

2. DEVELOPMENT OF TIME-COST MODEL AND ITS APPLICATION ON BUILDING PROJECTS

Our research [3, 5] analyzes different world research studies about construction time whose aim is to find an appropriate prognostic model for planning the sustainable construction deadline in the earliest phases of the project. By the end of the 1960s, the researches were focusing on the development of a numerical model which would enable a quick and real estimate or verification of construction time without applying detailed planning techniques. From the number of researches the model developed by Bromilow [6] stands out. In this model the project time is in relation with money in the exponential form $T=K*C^B$, K and B being constants [6, 7]. Constant K represents the number of working days required for the completion of a unit value work. This paper defines as a unit value work the value of *1.000.000,00 kunas* (Croatian currency – exchange rate *1 USD* is ca *4,6 kunas*). This model is logical and simple and it has later been used in many additional researches.

In 1991 Kaka and Price [8] examined and confirmed the credibility of the Bromilow model on a sample of 661 building construction stuctures and 140 roads constructed in Great Britain from 1984 until 1989. In order to adjust the model to the financial and constructing conditions qualitatively, the four classification criteria were proposed:

1. type of investment (public, private);
2. type of the project (buildings, civil engineering structures);
3. type of competition (open competition, selected competition, negotiated competition);
4. price (fixed, variable).

The type of competition was found to have no effect on the relationship.

Finally, six groups were modelled, as follows:

1. public buildings fixed price;
2. public buildings adjusted price;
3. private buildings fixed price;
4. private buildings adjusted price;
5. civil engineering fixed price;
6. civil engineering adjusted price.

The acquired values of the parameters K and B determined through linear regression of the logarithmic transformed data for six different types of projects are shown in Table 1.

Table 1. B and K values for the final six groups [8, page 398]

Effective groups	*B*	*K*
Public fixed	*0,3178*	*398,80*
Public adjusted	*0,2050*	*486,70*
Private fixed	*0,2120*	*274,40*
Private adjusted	*0,0817*	*491,22*
Civil fixed	*0,4693*	*258,10*
Civil adjusted	*0,4370*	*436,30*

The values of the coefficient R for six groups of projects are consecutively *0,76*; *0,68*; *0,49*; *0,61*; *0,84* and *0,97*. It means that only in the case of private buildings fixed price ($R=0,49$), as well as adjusted price ($R=0,61$) the model fitted data poorly, but for the public sector relationships are obviously reliable.

In 1994 Chan and Kumaraswamy [9] conducted a research on different types of structures built in Hong Kong from 1990 until 1993. The 111 projects were divided into three different categories: government buildings, private buildings and civil engineering structures.

The analysis in whole and the constants K and B in particular show different behaviour of these three categories. Government buildings and civil engineering structures fit into the model much better than private ones.

It was established that the values of the constants K and B are comparable to those obtained from the previous researches, the specific conditions taken into consideration.

The applicability of the model on the public sector structures in Malaysia was examined by Chan [10]. The sample comprised 51 civil engineering structures of public purpose built in the late 1980s and early 1990s. The following equation was obtained as a result:

$$T=269*C^{0,32} \quad (1)$$

The null hypothesis $H_0: \beta_1=0$, where β_1 is a slope, was tested and rejected in the mentioned researches. This confirmed the credibility of the original Bromilow's time-cost model [6] but it also showed that the values of the constants K and B should be separately examined due to different specific working conditions and general regional characteristics.

3. RESEARCH OF TIME-COST MODEL IN CROATIA

The first research related to development and application of time-cost model in Croatia was conducted from 2002 to 2004 on the civil engineering structures built from 1992 to 2003 [5]. This research was conducted on 107 structures sorted out into four categories: 41 state and local roads, 27 highway sections, 25 road structures (overpasses, tunnels, bridges, etc.) and 14 building structures (office buildings, residential buildings...). The constants K and B were determined and the time-cost model was defined for each category. A comparative analysis with the corresponding world results was also performed. The testing and rejecting of the null hypothesis confirmed the applicability of this model for the structures in Croatia. From 2005 to 2007 the second research on new multi-storey buildings projects was conducted.

3.1 Data gathering, size and structure of the samples

In both researches all the relevant data about structures, their contract and real prices and construction time were gathered by questionnaires sent to investors and contractors. Particular missing data were filled in after interviewing persons in charge of the projects. This paper shows a part of the research results related to combined residential and office multi-storey buildings of medium height (hereafter multi-storey buildings) and state roads and highway bonds (hereafter roads). The sample for roads comprises 27 road sections which were built in the past ten years (see later Table 2) while the sample for combined residential and office multi-storey buildings comprises 17 structures (see later Table 5) [5]. Due to a longer construction time, the price correction was made on the basis of price increase index obtained from the Croatian Central Bureau of Statistics [11]. The ratio between effectuated and contract construction time (T_E and T_C) has been determined to be maximum *2*. The idea is that higher ratio point to serious deviations in construction organization.

3.2 Time-cost model algorithm

The Bromilow model $T=K*C^B$ was used in the research and the constants *K* and *B* were being determined for specific market conditions in Croatia. The process of defining the time-cost model follows subsequent steps [2, 12]:

1) Price correction using price increase index in relation to the monitored period and exhibition of prices in corresponding currency.
2) Calculation of price and time natural logarithms – $ln\ C_C$, $ln\ T_C$, $ln\ C_E$ and $ln\ T_E$, where C_C and T_C are contract values and C_E and T_E are effectuated values.
3) Verification of linear dependence between the variables price – time:
   a) by visual appraisal of $x – y$ graph,
   b) by quantifying the intensity of correlation using the regression coefficient *R*.
4) Conducting regression analysis and establishing the equation of assessor's straight line.
5) Testing of the null hypothesis $H_0 : \beta_1=0$.
6) Determining the confidence interval for slope and intercept.
7) Calculating the residual and determination coefficient.
8) Verification of the results using residual by drawing and appraisal of $y – e$ graph, that is by appraising the variable value *y* according to the corresponding residual. If the dots on the graph do not have a significant arrangement or pattern, but are randomly scattered about, it is a case of random mistakes.
9) If the model is assessed as acceptable based on the previous one, the assessments for slope and intercept indicators the maximal and minimal values from the confidence interval are adopted.
10) The values of constants K_C, B_C, K_E and B_E are calculated by including the assessed values of slope and intercept indicators, then the following stands:

$$ln\ K = \beta_0\,,\quad K = e^{\beta_0}\,,\ \ B = \beta_1 \qquad (2)$$

3.3 Gathered data processing

The gathered data for each of the two chosen groups were processed by applying statistics software Statistica. Money values are expressed in billions of Croatian kunas (*1 Euro = 7,50 kunas*) [13], and the construction time *T* is expressed in days.

Effectuated values of road projects for the whole database which consists of 27 projects, are shown in Table 2. In this case $R = 0,71$; $R^2 = 0,50$ and adjusted determination coefficient is $AR^2 = 0,48$ (Table 3). According to Eq. (2), effectuated values are $K = 58$ and $B = 0,50$. At the same time the contract values are $R = 0,79$; $R^2 = 0,63$ and $AR^2 = 0,61$, $K = 77$ and $B = 0,49$ (Table 3), but for the practical usage, the effectuated values are of interest.

Although rather low, the obtained effectuated coefficient values allow the usage of linear regression. Verification of the null hypothesis by *F*-test and level of significance $\alpha=0,05$ was performed. By its rejection, the linear dependence of the variables *T* and *C* as well as the applicability of the time-cost model were confirmed.

Table 2. Road section database

Road section	Construction time (days)		Adjusted construction cost (in 1.000.000,00 kunas)	
	Contracted (T_C)	Effectuated (T_E)	Contracted (C_C)	Effectuated (C_E)
1.	150	150	3,49981370	5,781712968
2.	127	187	15,45795584	21,76928432
3.	100	130	2,89203311	4,150795489
4.	240	120	17,11793995	19,08494873
5.	690	630	39,40539173	49,10692188
6.	690	630	50,41892695	61,91113188
7.	600	360	40,19435850	43,49734927
8.	690	630	67,76307009	86,53941717
9.	660	510	23,76761504	27,09637622
10.	420	330	10,99517496	12,82632885
11.	660	510	30,42415977	35,63399151
12.	840	840	50,03278843	81,39387301
13.	300	270	10,65491973	16,21764748
14.	660	660	34,34429070	42,86690144
15.	600	360	78,37899907	81,81004209
16.	240	240	11,46630631	15,03228167
17.	240	180	10,36612941	17,95735894
18.	600	360	82,39843492	87,57538804
19.	660	510	41,14948660	45,97050522
20.	240	240	13,08294188	17,6953165
21.	840	840	64,04188733	103,0691374
22.	240	240	15,02465738	20,04340155
23.	240	60	13,30863593	22,52441878
24.	240	180	60,79283718	81,42643707
25.	420	440	97,00723927	156,6008169
26.	80	108	2,22346492	2,147920146
27.	480	1440	189,97372583	144,8768644

Table 3. Parameters for road data base

Parameters	Contract values	Effectuated values
R	0,79	0,71
R^2	0,63	0,50
AR^2	0,61	0,48
β_0	4,349	4,067
β_1	0,487	0,496
K	77	58
B	0,49	0,50
$T = K{*}C^B$	$T = 77{*}C^{0,49}$	$T = 58{*}C^{0,50}$

The same simple linear regression analysis was made also for the data base without the road section *27* because of the ratio between effectuated and contract construction time (T_E and T_C) has been determined to be maximum 2, and in this case is 3. In this case $R=0,68$, $R^2=0,46$ and adjusted determination coefficient is $AR^2=0,44$, $K=66$, $B=0,45$ for the effectuated values and $R=0,82$, $R^2=0,68$ and $AR^2=0,66$, $K=67$ and $B=0,54$ for contract values (Figure 1 and Table 4.). Better contract results can be explained with more predictable circumstances and lower risks in this phase than in construction phase.

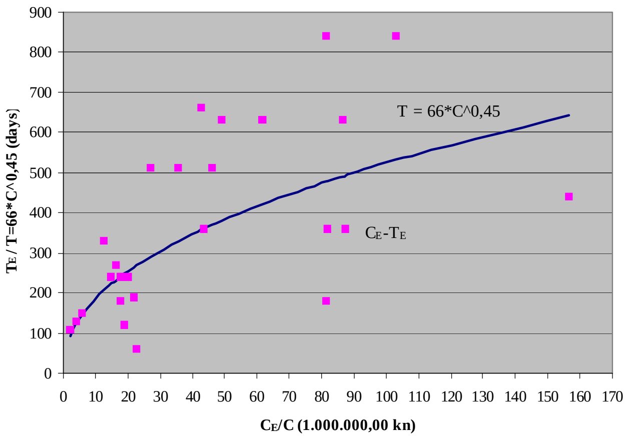

*Fig. 1 Scatter diagram C_E-T_E for highways and express ways, with the road section 27 excluded and graph C-T, T=66*C^0,45*

Table 4. Parameters for road data base with the road section 27 excluded

Parameters	Contract values	Effectuated values
R	0,82	0,68
R^2	0,68	0,46
AR^2	0,66	0,44
β_0	4,200	4,185
β_1	0,540	0,453
K	67	66
B	0,54	0,45
$T = K{*}C^B$	$T = 67{*}C^{0,49}$	$T = 66{*}C^{0,50}$

The same simple linear regression analysis was made also for the data base of residential and official multi-storey buildings projects (Table 5). All the prices were corrected by a statistical index of price increase [11]. Figure 2 shows the graph $ln\ C_E$ - $ln\ T_E$, that is, a functional dependence of price – time for effectuated values. The coefficients by which the verification of linear regression applicability is done here are of higher value. The correlation coefficient $R=0,89$, the determination coefficient $R^2=0,80$ and the adjusted determination coefficient is $AR^2=0,78$ for the effectuated values. Here, the contract values are something lower, $R=0,88$, $R^2=0,77$ and $AR^2=0,75$ (see later Table 6). The null hypothesis was rejected after verification through F-test.

Table 5. Building database

Buildin g	Construction time (days)		Adjusted construction cost (n 1.000.000,00 kunas)	
	Contracted (T_C)	Effectuated (T_E)	Contracted (C_C)	Effectuated (C_E)
1	600	900	44,77803351	46,84513335
2	540	1080	30,68959045	40,75425830
3	390	450	19,21791336	16,32079391
4	270	300	6,54756998	6,54756998
5	180	195	4,56730372	4,56730372
6	450	450	27,93577899	27,93577899
7	360	360	16,84210601	16,20800646
8	150	107	1,82664550	1,63571045
9	365	365	8,86413043	8,86413043
10	75	135	1,94958419	2,59383065
11	395	365	12,74977514	12,74977514
12	240	275	7,54027290	8,49088090
13	210	260	18,82505400	19,88705400
14	420	420	48,14000000	48,14000000
15	480	540	20,89000000	20,51000000
16	360	360	15,43000000	15,43000000
17	330	330	12,48000000	12,48000000

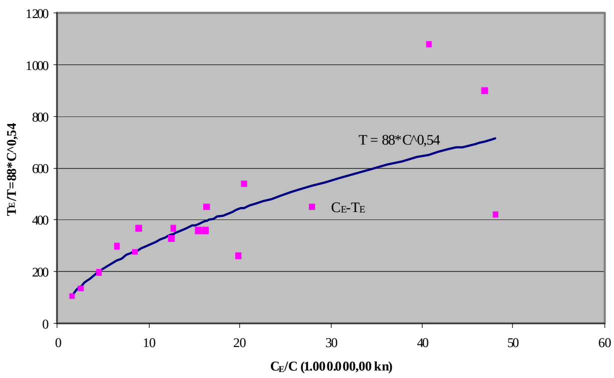

*Fig. 2 Scatter diagram C_E-T_E for buildings and graph C-T, T=88*C^0,54*

3.4 Survey and analysis of obtained results

3.4.1 Roads

Time-cost relation for effectuated values of road construction time for 27 road sections from initial database is:

$$T = 58{*}C^{0,50} \tag{3}$$

At the same time, the planned values from the construction contract show a somewhat different relation:

$$T = 77*C^{0,49} \quad (4)$$

The difference in value of the constant K shows that a longer estimated contract time was anticipated for work completion having in this case the money value unit *1.000.000,00 kunas*, so that it could be said the construction was built somewhat faster than planned. When the subjects are highways this phenomenon is really present in practice. Yet, previous research [5] has shown that the state roads trend is exactly the opposite, which explains the indicator of the total overrun of road construction time.

If the sample is corrected in a way that the road section number *27* is excluded (the ratio between the effectuated and contracted construction time is *3*), the relation for the effectuated values is:

$$T = 66*C^{0,45} \quad (5)$$

while the relation for the contract values is:

$$T = 67*C^{0,54} \quad (6)$$

It can be seen that approximately the same values of the constant K were obtained both for the fixed and the effectuated values, while the constant B at effectuated values is somewhat lower than at fixed values, that is, the obtained value points out the lesser influence of project complexity to the construction time than it is expected.

While the research was being conducted it was established that the ratio T/T_C (sustainable by calculations and contract construction time) according to the contract price C can be successfully approximated by a straight line with a very high determination coefficient $R^2=0,82$ as it is shown in Figure 3. The straight line shows the tendency of increase the ratio T/T_C with increase of the price of the structure.

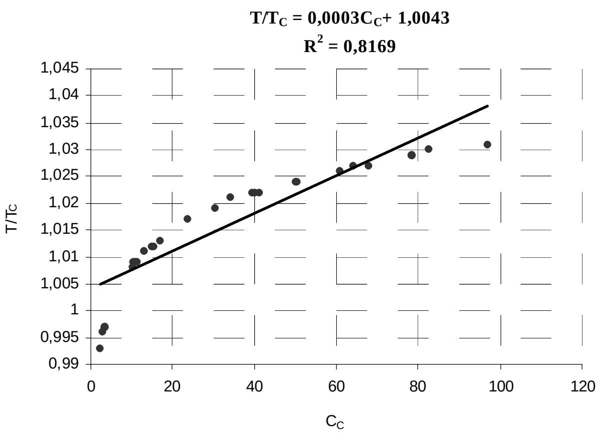

Fig. 3 Graph C_C - T/T_C for roads of higher importance

3.4.2 Multi-storey buildings

The effectuated work values and construction time of multi-storey buildings are connected with the relation (Table 6):

$$T = 88*C^{0,54} \quad (7)$$

The constants K and B obtained at contract values have different amounts while the upper relation is changed into the following form (Table 6):

$$T = 91*C^{0,48} \quad (8)$$

From the two above mentioned relations it can be seen that when dealing with residential and office buildings the difference of the constant K between the effectuated and contract values is significantly smaller than with roads, while the difference of the constant B value is somewhat larger, but not significantly (Table 6). It can be namely concluded from the relation of effectuated values of construction time that the influence of the project complexity on construction time is larger than the one foreseen by the estimated contract construction time.

Table 6. Parameters for building data base

Parameters	*Contract values*	*Effectuated values*
R	*0,88*	*0,89*
R^2	*0,77*	*0,80*
AR^2	*0,75*	*0,78*
β_0	*4,51*	*4,47*
β_1	*0,48*	*0,54*
K	**91,00**	**88,00**
B	**0,48**	**0,54**
$T = K*C^B$	$T = 91*C^{0,48}$	$T = 88*C^{0,54}$

By residential and office multi-storey buildings it was concluded that the average fixed time is for *16%* lesser than the effectuated one. This relation resembles the calculated figures obtained by applying the time-cost model by which the sustainable time is for ca *13%* longer than the one from the contract. The average sustainable construction time obtained by applying the time-cost model is approximately the same as the effectuated one.

Comparing the relation between C_C and T/T_C for multi-storey buildings it was established that it was possible to approximate that relation with a straight line shown in Figure 4. Just like at roads (Figure 3), the trend of the increase of the relation T/T_C is obvious, but the increase is milder. It means that by increase of the fixed price the relation between the calculated sustainable and the fixed construction time rises. The approximation was obtained with a very high coefficient of determination $R^2=0.82$.

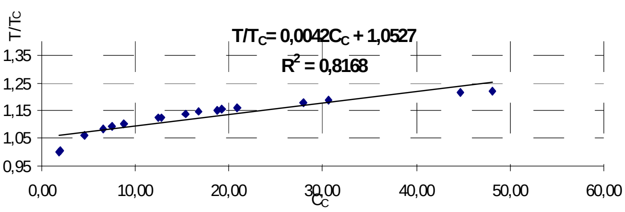

Fig. 4 Graph C_C - T/T_C for multi-storey buildings

Verification of regression model hypothesis was performed by checking the diagram of residuals vs. predicted values. The conducted verifications of linear dependence, null hypothesis and residuals justify the application of the time-cost model for analyzing the category of structures in Croatia.

3.5 Relation proposal for calculating the sustainable construction time

Based upon the previously displayed analysis of roads, the following relation for calculating construction time is proposed:

$$T = 66*C^{0,45} \quad (9)$$

The following relation for calculating construction time is proposed for residential and office multi-storey buildings:

$$T = 88*C^{0,54} \quad (10)$$

The proposed values can be used for predicting construction time in the early project phases under regular circumstances without extreme influences.

The models presented with relations (9) and (10) both have no extreme influences and refer to the regular level of the construction risk.

4. MODEL APPLICATIONS FOR EARLY ANTICIPATION OF SUSTAINABLE CONSTRUCTION TIME

The obtained relations between construction time and cost from Section 3 are average figures which can be effectuated under average circumstances. They can be used for duration planning in the early project phases when initial cost estimates are known or as a basis for contracting business when frame price is also known. It makes sense to additionally correct the obtained figures when finally the sustainable contraction times are being determined. Our long-time research [2] has clearly confirmed the pattern of some phenomena exclusively related to the way of effectuating the project. The three following factors which can significantly change the planned deadline stand out from the analysis of the forty potential internal or external factors:

* Proportion of project changes during its carrying out,
* Project management quality,
* More significant problems with finances.

Apart from these three factors which are more or less present at every project, it is also very important to know whether it is the matter of a public or of a private project. As a rule, private projects have more efficient investors, so the construction time is shorter. Our research shows that this knowledge can be applied to building structures in a way that the planned construction time from the proposed equation is reduced by correction coefficient. Opposed to multi-storey buildings, the roads are regionally constructed as public projects in more than *90%* of cases and the influence on planning and sustaining the deadline depends on the interest and the influence of the governing policy on the specific project. If the politics is interested in the project, the deadline can be planned as if the projects were private.

When all the above mentioned insights are applied to building structures with supposition that the duration interval T has particular limiting values T [*60*, *700*] in days which refer to most projects, the equation for determining construction time is as follows:

$$T = k_{ch}*k_{pm}*k_f*k_0*(K*C^B) \quad (11)$$

with k_{ch}, k_{pm}, k_f and k_0 being correction coefficients for changes, project management, financial problems and ownership (private, public, combined) respectively. Proposed values for correction coefficients, based on initial research [3, 5], are shown in Table 7.

Table 7. Internal and external factor correction coefficients

Changes	*large*	*medium*	*small*
	1,50	*1,25*	*1,00*
Project management	*excellent*	*average*	*poor*
	0,80	*1,00*	*1,20*
Financial problems	*grave*	*moderate*	*no*
	1,35	*1,05*	*1,00*
Ownership	*private*	*combined*	*public*
	0,90	*1,00*	*1,10*

The least favourable single and the common influence of correction coefficients on the building construction project duration prolongation are shown in Figure 5.

All those coefficients were obtained by preliminary research [3, 5] and they are of rough value. The values were obtained by interviewing the competent experts who gained experience from the previously conducted similar projects. Based on the proposed classification, each of the interviewed experts had to point out the key factors and make assessment of the influence in question on the deadline prolongation in percentage and in relation to the planned values. The risk factors which were pointed out by most of the experts were selected and the assessed values were used in pessimist, optimist and mean value determination.

The continuation of research requires their more correct values and correlations as well as the possible influence of other factors. Project data gathering was conducted within the scientific and research project Ref. [3]. However, it can be already established at present that the extreme negative influence can double the construction time which was calculated by relation from the Section 4.5, while the construction time can be reduced by 1/3 if it is under a positive influence. This is a significant message to the investors which should be taken into consideration when determining the deadline.

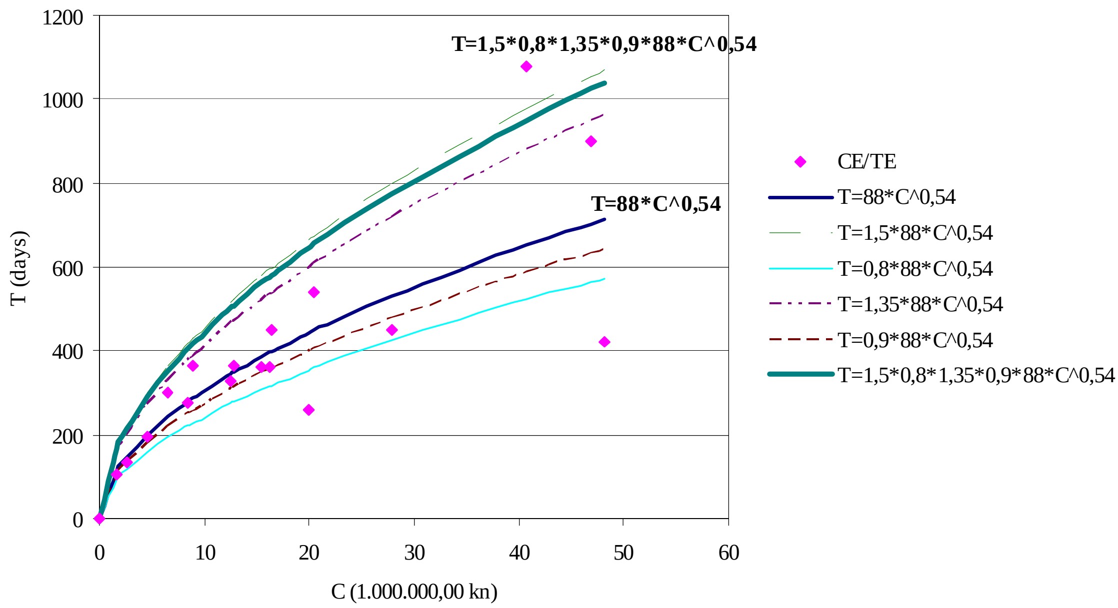

Fig. 5 Graphs C-T for buildings, with correction coefficients included

5. DISCUSSION OF RESULTS AND CONCLUSIONS

The conducted research shows that it is possible to determine the methodology for calculating construction time. This methodology can be used in the early phases of the project and help in determining sustainable deadlines when closing the contract. This provides both the investor and the contractor a credible basis for final negotiations and determination of fixed time. The analysis of the obtained results offers the following conclusions:

1. Construction time for residential and office multi-storey buildings is negotiated in ca *13-16%* shorter period of time than the required one, with a maximum deviation range of *0,783* to *2,045* and a standard deviation of *0,340*. For constructing roads of higher importance a *15-22%* longer period of time is negotiated, with a maximum deviation range from the average of *0,428* to *1,884* and a standard deviation of *0,401*. This actually reflects the political interest influencing on a faster work completion on public project of special interest.
2. Constant *K* is higher for residential and office multi-storey buildings than it is for the roads. This can be explained by numerosity and variety of handicraft work in building construction and by a larger number of sub-contractors.
3. There is no significant difference in value of constant *B* for either of the two groups of projects. That means that the work value has the same influence on construction duration time.
4. When compared to the corresponding results from abroad, the values of constants *K* and *B* obtained by this research are larger. That indicates to a possible low productivity which could be the result of more poorly organized work or of an out-of-date technology.
5. The models $T=66*C^{0,45}$ and $T=88*C^{0,54}$ are the most important goal of this research. The first model is applied when estimating / assessing the higher rank road construction time under regular risk level conditions. The second model is applied on building construction projects, also under regular risk level conditions.
6. The $T=k_{ch}*k_{pm}*k_f*k_o*(K*C^B)$ model application is fully justified under conditions of risks deviating from the regular level. However, the verified application of this equation requires additional research in order to estimate a more accurate correction coefficient values.

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TIME-COST MODEL GRAĐENJA U HRVATSKOJ

SAŽETAK

U radu se razmatra primjenjivost time-cost modela $T = K*C^B$ za izračunavanje održivog vremena građenja za građevinske projekte u Hrvatskoj. Vrijeme je iskazano kao funkcija vrijednosti projekta. Konstante K i B zavise o gospodarskim značajkama zemlje te ih treba posebno izračunati za tu zemlju ili za neko šire područje sa sličnim ekonomskim karakteristikama. U radu je modeliranje izvršeno za dvije grupe objekata - ceste i stambeno-poslovne višekatnice. Dobiveni rezultati su analizirani i uspoređeni s odgovarajućim inozemnim rezultatima, što upućuje na zaključke u vezi produktivnosti.

Ključne riječi: *vrijeme izgradnje, time-cost model, konstante K i B, linearna regresijska analiza, građevinski projekti.*