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SOFTWARE FOR PROJECT RELIABILITY ESTIMATION AND RISK EVALUATION

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Abstract. *The contribution presents a model that is able to simulate construction duration and cost for a building project. This model predicts set of expected project costs and duration schedule depending on input parameters such as production speed, scope of work, time schedule, bonding conditions, maximum and minimum deviations from scope of work and production speed. Construction cost and time models are, in many ways, useful tools in project management. Clients are able to make proper decisions about the time and cost schedules of their investments. Consequently, building contractors are able to schedule predicted project cost and duration before any decision is finalized.*

1 INTRODUCTION

The simulation of the construction process (construction activities on the basis of production speed) makes it possible to *monitor the reliability* of expected time schedule and total cost depending on such input parameters as production speed, scope of work, time schedule, bonding conditions, maximum and minimum deviations from scope of work and production speed.

2 FIELD OF APPLICATIONS

The simulation model is useful at many levels of project management. The possible fields of application are shown in the table 1.

Tab. 1 Fields of application.

Project phase	***User***	***Field of application***
Preparation phase	*Client*	Decisions about realization of intentions.
	Competitor	Cost assessment and inference of bid price.
	Submitter	Comparative base.
Construction phase	*Building contractor*	Dynamic schedule.
		Detailed calculation of cost and time schedule of construction activities.
		Optimization of construction process.
	Building contractor & submitter	Decrease of the number of claims among building contractor, building subcontractors and submitter.
		Information source usable in realization of future projects.

3 METHODOLOGICAL AND CONCEPTUAL APPROACH

The application software carries out on the basis of production speed, analysis of duration and cost simulations of construction activities. On the basis of a statistical evaluation of enacted simulations a program algorithm calculates the assumed cost and time frames of particular construction activities.

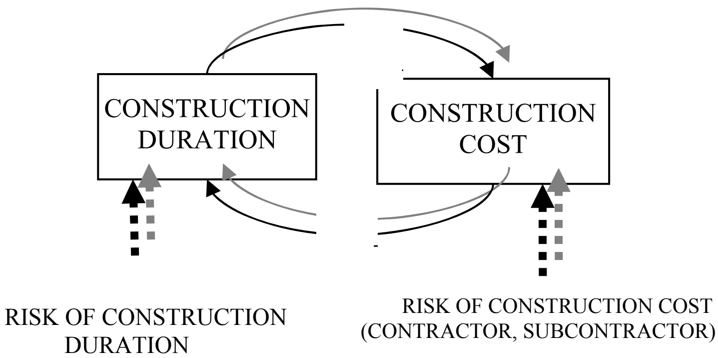


Fig. 1 Interactions between construction duration and construction cost.

It is a general principle that the interactions between time and cost create a positive dependence. Lengthening or shortening of construction duration leads to the increases of total construction cost. The graphic in Figure 1 illustrates the above statement.

However there exist a lot of problems in applying the determination of construction duration. There is a possible appearance of risks which affect termination date of a building project, for example shortening or lengthening of construction duration incurred by climatic influences, disorder in supplies of materials and components, inadequacies ascertained on acceptance of input materials, etc. Seemingly elementary and transparent situations are further complicated in many practical cases by the fact, that the bindings between illustrated elements (*Time duration, Cost)* are able to change polarity over time. It is likely to see a change to negative link from positive link between elements *Time duration* and *Cost*. Higher cost could objectively negatively affect construction duration. It deals with a situation, in which these is used a cost-expensive component with a shorter time schedule of works on a building site (prefabrication, in advance ready fabrication works, etc.). In respect of the fact, that the mentioned situation is possible in all works, the calculation is very highly burdened by these influences, which are difficult to manage by common calculation methods (Beran, 2002; Haas, 1981).

4 GENERAL PROBLEM FORMULATION

The initiation of the building project simulation it is necessary to formulate the problem as such. The application receives input data through *Module of input data* (see Table 6, 7, 8, 9), which defines particular construction activities (1), volume $\boldsymbol{Q}$ of these particular construction

Tab. 2 Dynamic progress chart of building project.

Activity	Scope of work	Production speed	Time duration	Start	End	Day																								
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ground works	150	33	5	2	6		33	33	33	33	19																			
Water connection	191	23	10	8	17								23	22	22	21	20	19	19	18	17	10								
Sewerage connection	207	55	4	9	12									55	64	74	15													
Electricity connection	93	93	1	19	19																			93						
Bottom construction	456	36	13	13	25													36	36	37	37	37	38	38	38	39	39	40	40	1
Dumping place	50	50	1	4	4				50																					
Overhead construction	1010	42	14	26	39																									
Roof	308	48	5	41	45																									
Inside parget	66	32	3	47	49																									
Facade rendering	63	30	3	51	53																									
Completing works	40	7	6	50	55																									
Demands of sources through time Q'(t)						0	33	33	83	33	19	0	23	77	85	95	35	55	55	55	54	48	38	131	38	39	39	40	40	1
Total demands of sources through time Q(t)						0	33	66	149	182	200	200	224	301	386	481	516	571	626	680	735	782	820	951	989	1 028	1 068	1 107	1 147	1 148

Key:
… Noncritical activity
… Critical activity
… Total reserve
… Waiting for activity
… Waiting for activity - on critical way

activities in physical or financial units, its production speed $\boldsymbol{v}$ and bonding conditions $\therefore \boldsymbol{D}_{\text{connection activities}}$ linking particular activities. $\boldsymbol{TAB}_{\text{project}}$ characterizes the calculation as a meta problem called *Dynamic Harmonogram* (flow-sheet). *N* characterizes generally sequential networks N_i (Beran, 2002). The set expression is given as

$$\boldsymbol{TAB}_{\text{project}} = \{N_i \,\big|\, [\boldsymbol{D} = f\,(\boldsymbol{Q}|risk,\ \boldsymbol{v}|risk, \therefore \boldsymbol{D}_{\text{connection activities}})]\ ,\ i = 1,..\ \} \quad (1)$$

where *i* are partial processes and ***D*** is as set of activity durations, *risk* influence is conditioned externality (see Fig. 1). The notation is completed with conditionality of breach of supposed input parameters of scope of work and production speed. The Module of input data is illustrated in the subchapter *8 SW support*.

A practical solution of the calculation according to the dynamic progress chart (1) is based on the input of work volume, production speed and a time schedule of particular activities. Time duration in the dynamic progress chart is calculated as the quotient of quantities ***Q*** a ***v*** or more precisely $D_i = Q_i/v_i$. Input data included in *Module of input data* in sheet *Connection activities* define bonding conditions among particular production activities. The sheets called *Deviations of project parameters 1 and 2* contain input data about minimum / maximum deviations of scope of work and production speed of particular activities based on expected parameters of the building process.

5 SOLUTION AND EXAMPLE

On the basis of an ordinary Excel VBA application the algorithm makes it possible to calculate an instant dynamic progress chart of the building project that includes a time schedule of resources. The dynamic progress chart is in terms of notation (1) completed by

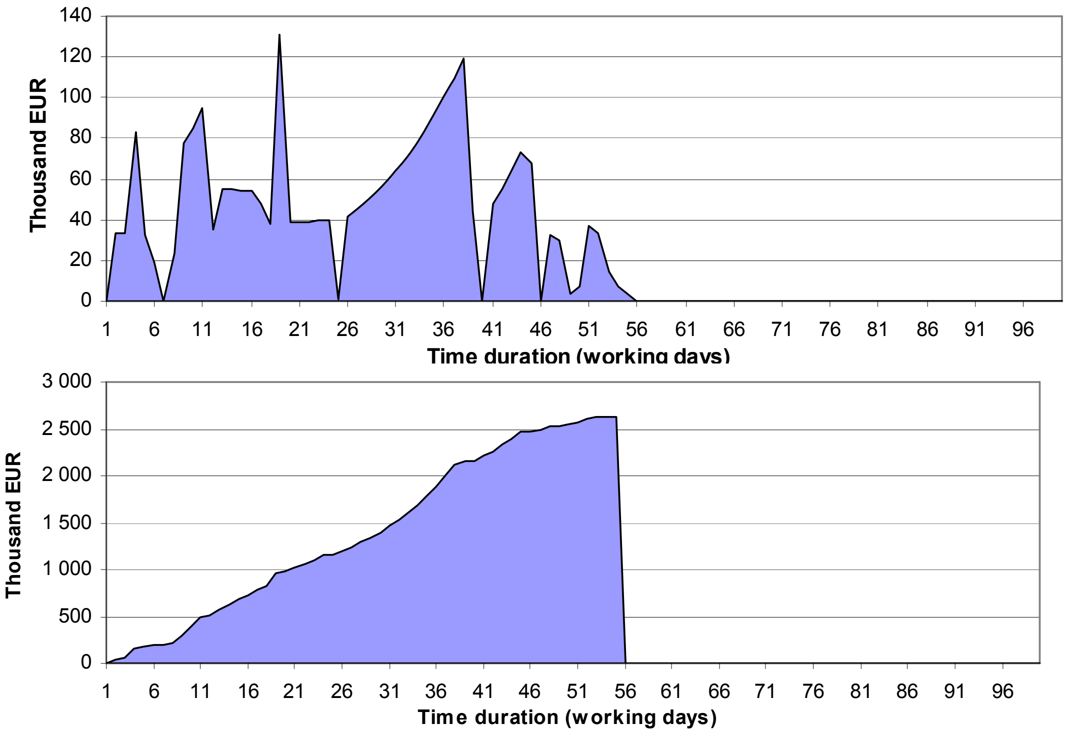


Fig. 2 Required cash flow of capital needed from the start to the end of construction and cumulative need of capital.

means of differences calculated on the basis of a common progress chart. Calculation is based on production speeds and individual activities, which are described in columns *Start* and *End* (Tab. 2), which represent bindings between individual activities. It factually represents relations between declared function $f(\boldsymbol{Q}|risk,\ \boldsymbol{v}|risk, \therefore \boldsymbol{D}_{\text{connection activities}})$ from notation (1) and composition of task as a consecutive process on the base of time duration of individual processes N [$\boldsymbol{D}$] (Beran, 2005); (Beran, 2002); (Heralová, 2002).

The dynamic progress chart creates a comprehensive methodically uniform model. Among the model's outputs belong information about the start and end terms of production activities and information about cost schedules. The application creates graphic visualization of resources demand in time see Fig. 2.

The question of continuity of project realization is interconnected with cost-cutting management measures of construction cost. The varying construction speed evokes changes in construction costs. The flow of construction costs are a significant indicator of economy of capital employment.

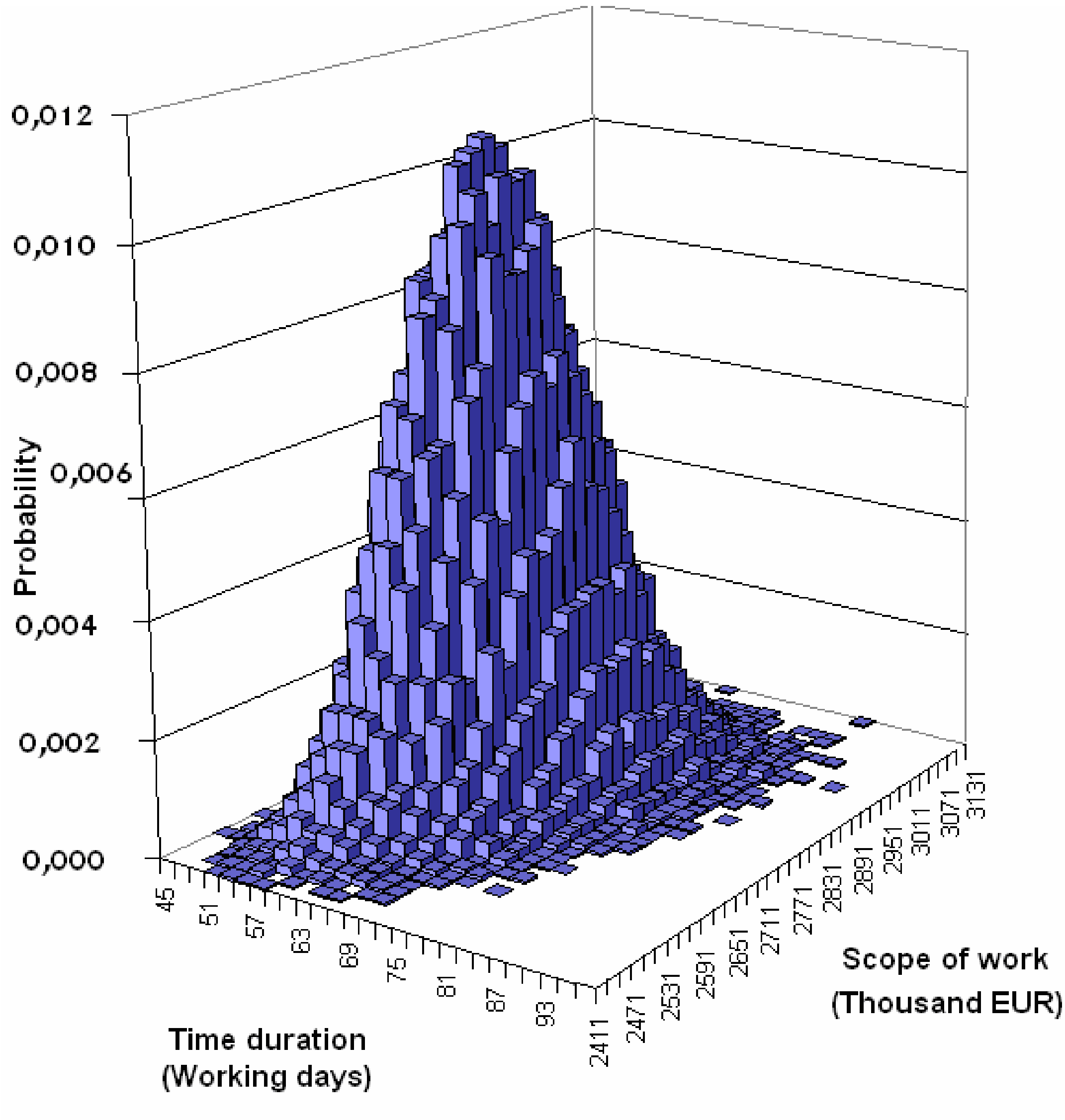


Fig. 3 Example of 3D probability bar chart as expression on the basis of (1).

The described calculation and software application is useful for evaluation of bid proposals of investment projects. The approach carries out two dimensional simulation. The projects described in propositions *time* and *costs*, will be labeled as a predefined project. The discrete probabilistic variables (T; C) obtain values (t_i ; c_j). We will write $\mathbf{P}(T = t_i; C = c_j) = p_{ij}$.

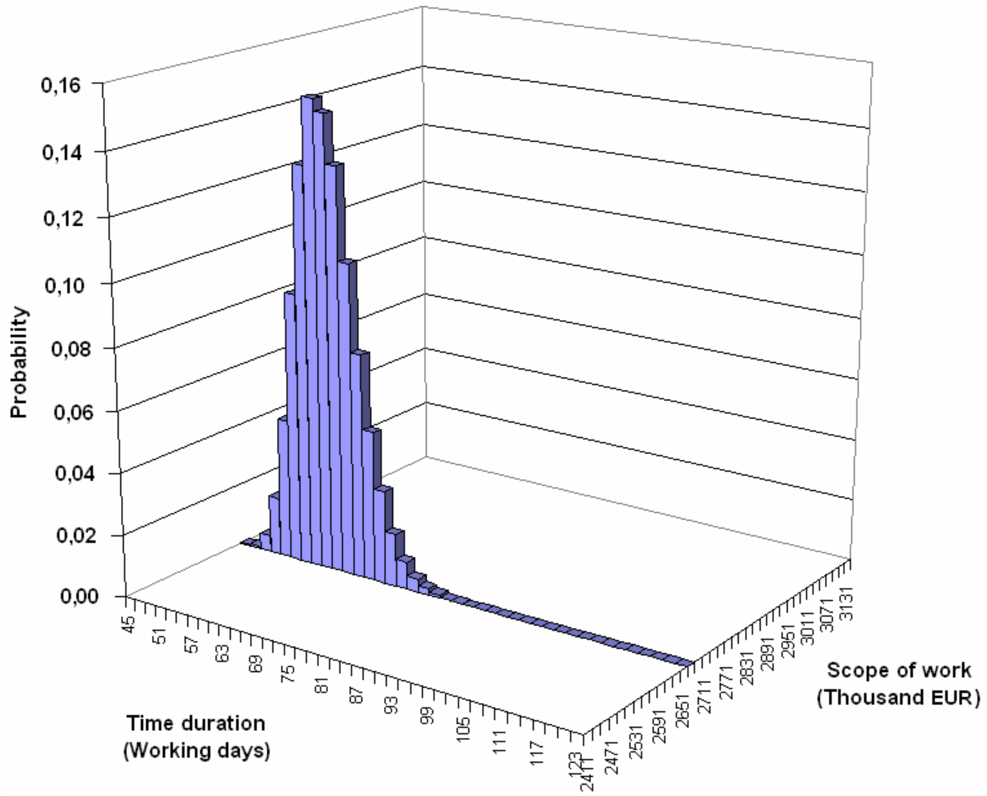


Fig. 4 Probability 3D bar chart for construction project with fixed cost scope *C*.

On this basis of predefined projects data the additive input information about *minimum and maximum deviations* (see subchapeter *8. Software Support*). SW application carries out simulation of the presumed development of the examined construction phase, the construction project as a whole, or just to a set of construction activities. It is possible to identify the effects of changes, read management changes, on the scope of particular jobs (construction activities) and their probability (reliability) of proposed (read contracted) finishing deadline t_{fin} and proposed contracting limit of cost c_{fin} . In general we are looking for acceptable

$$F(t_{fin}; c_{fin}) = \sum_{t} \sum_{c} \mathbf{P}(T < t_{fin}; C < c_{fin}) \quad \text{for chosen project activities } A_k \qquad (2)$$

or their activity sets A_k, A_l,… A_x, functionality-designed into network.

The results of particular simulations

$$\mathbf{P}(T; C) = \mathbf{P}(sim\boldsymbol{TAB}_{\text{project}}(T; C)) \qquad (2a)$$

for example mentioned further is $T \in$ <45;89> and $C \in$ <2411;3131>. Simulation data are continuously recorded on the basis of (1), (Beran, 2002). The simulation is based on the time schedule given in Table 2. Obtainable is the ranging of 50 000 simulations into 30x30 categories. When a simulation is finished, the recorded data serve as a basis for statistical analysis of construction processes. Data file serves for final analysis and inter alia is the basis for modified 3D visualization similar to Fig. 3. The calculation of expected or fixed probability starts, ends and reserves given are the results in Fig. 4 and Fig. 5.

In Tab. 3 are structured data of the comprehensive simulation example. The particular points ate calculated as a construction bid proposal described underneath by simulation study shows, how far the intended finishing date and cost are actually competitive and realistic.

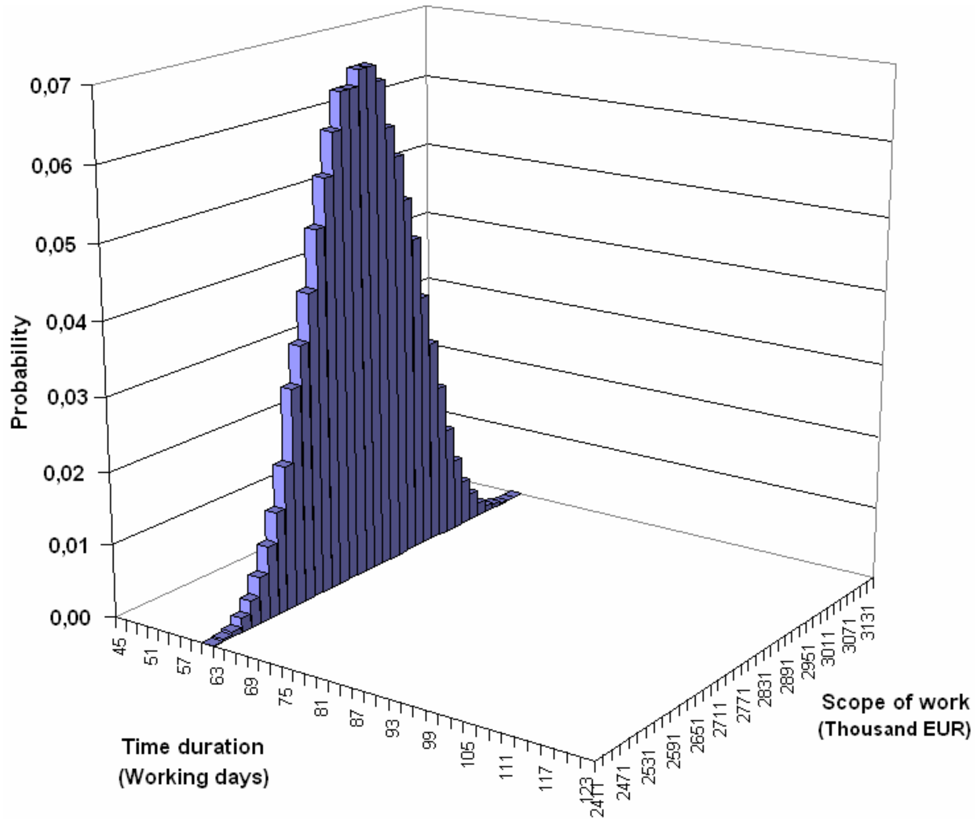


Fig. 5 Probability 3D bar chart for construction project with fixed time duration *T*.

$$\mathbf{P}(T_{(45,89)};\, C_{(2411,3131)}) = \mathbf{P}(sim\boldsymbol{TAB}_{\text{ project}}\,(T;\, C)) =$$

$$\mathbf{P}\,\Big(sim\{N_i \,\Big|\, [\boldsymbol{D} = f\,(\boldsymbol{Q}|risk,\ \boldsymbol{v}|risk, \therefore \boldsymbol{D}_{\text{ connection activities}})]\ ,$$

$$\text{for subprojects or sub activities } \ i = 1,..\ \}\Big) \qquad (2b).$$

The construction project (Tománková, 2003) is proposed in time schedule and scope of work as given in 3D bar chart. The ellipse in Table 3 shows the shift of probability in time and costs. Using this approach it is possible to specify more exactly the results of simulations. Occurrence frequencies of particular scenarios of building project bid are comparable. The highest values of simulation frequencies in 3D bar graph lead to probabilities of potential success scenarios for the construction project. In this case the building project will be realized with satisfied commercial probability within the range of 57 to 59 days and its construction cost is given in the range of 2 731 to 2 751 thousand EUR.

Within the framework of simulation of building project it is common that the calculation finds out the unique regular solution. The example of 3D probability bar chart with unique regular solution is shown in Figure 3.

In case of complicated bonding conditions and other additional interdependences among particular activities, the solution of the simulation may not be unique.

Tab. 3 The example of 3D bar chart, that illustrates the result of 50 000 simulations.

Classes	Scope of work (Thousand EUR)																																				Total
Time duration (day)	2411	2431	2451	2471	2491	2511	2531	2551	2571	2591	2611	2631	2651	2671	2691	2711	2731	2751	2771	2791	2811	2831	2851	2871	2891	2911	2931	2951	2971	2991	3011	3031	3051	3071	3091	3111	3131	
45					1			1						1			1			1																		5
47					2	4	1	1	5	1	2	1	1	2	2	1	1							2														26
49		1	2	4	6	10	6	14	17	17	19	19	25	18	20	21	14	8	13	7	5	5	3	2	1	1												258
51	1	3	5	8	19	23	33	42	42	68	68	71	74	69	81	67	41	54	60	30	31	19	10	7	9	2		1	2									940
53	2	3	6	10	24	41	64	81	101	138	136	157	180	170	191	158	145	122	94	113	84	86	56	43	30	16	8	8		2		1						2 270
55	1	5	2	13	34	53	77	110	135	201	224	268	313	317	336	336	307	287	267	253	205	177	127	127	75	56	34	23	10	6	5			2				4 386
57	1		8	20	26	63	87	111	182	240	299	351	373	446	450	454	478	477	458	383	341	286	263	205	141	111	87	52	26	23	9	3	2	1				6 457
59		1	2	12	28	46	87	110	156	245	298	342	421	433	480	535	543	552	542	469	402	397	351	294	250	174	129	92	58	31	17	10	6	2	1			7 516
61			4	9	21	33	50	98	140	212	257	313	319	410	491	514	485	522	515	520	480	434	382	298	252	197	141	87	60	28	22	10	3	1	2			7 310
63		1	1	8	10	23	47	56	93	137	178	230	279	355	378	465	447	445	462	480	415	383	348	315	278	228	170	112	83	53	32	15	2	2			1	6 532
65		1		6	8	10	22	40	56	106	137	130	210	259	251	308	341	364	351	374	353	334	290	277	245	168	154	97	65	41	22	13	12	3	1			5 049
67			1	3	3	4	12	20	32	58	69	97	155	139	194	224	219	233	270	304	262	255	232	208	169	161	106	83	51	29	25	11	5	2	1			3 637
69			1	2	1	2	6	7	22	34	39	62	74	96	106	114	156	170	171	179	181	169	186	158	115	107	96	52	54	31	23	8	3	2	1			2 428
71						2	2	6	4	17	13	25	24	44	52	74	81	101	119	113	118	127	104	115	91	84	58	54	29	22	12	5	6	2	3			1 507
73							1	4	1	7	9	13	24	23	29	37	36	59	70	50	70	65	60	65	49	53	34	35	22	16	13	3	2	2				852
75									1	2	2	2	7	11	14	12	20	25	25	33	39	36	38	44	32	28	29	20	8	11	2	1						442
77							1		2		1	1	1	5	4	5	6	16	14	13	15	12	17	23	14	15	11	11	14	5	1	5		1				213
79											1			2	1	1	7	2	5	5	5	9	10	6	7	12	8	4	3	5	5	3		1				102
81															2	1	1	1	2	4	2	4	2	4	5	3	9	3	2	2	1		2	1			1	52
83																		1	3				1	1	1		1	2			1							11
85																					1			2				2			1							6
87																																						0
89																												1										1
Total	5	15	32	95	183	314	496	701	989	1 483	1 752	2 082	2 480	2 800	3 082	3 327	3 329	3 439	3 441	3 331	3 009	2 798	2 480	2 196	1 764	1 416	1 075	739	487	305	191	88	43	22	9	0	2	50 000

The Figure 6 and the Figure 6a present the building project; in which input parameters contain specific interdependence within the first activity (ground works). Compare these results to Fig. 3. In the event that the first activity should take more than 25 days, the building

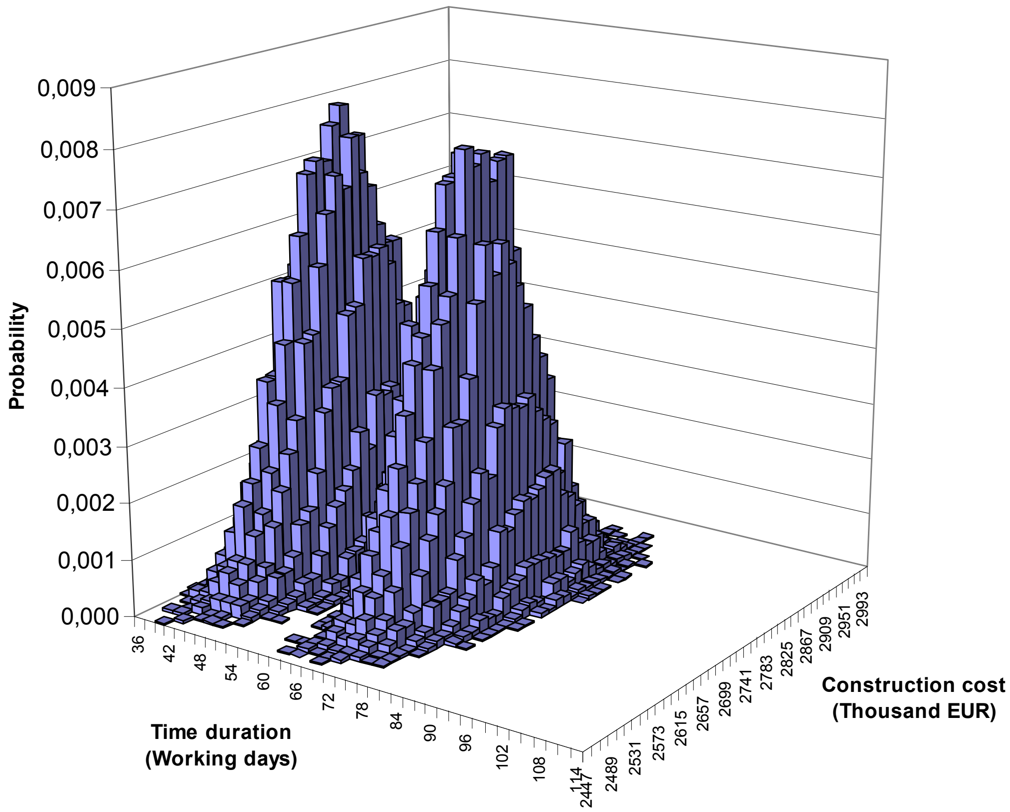


Fig. 6 Example of 3D probability bar chart with heterogeneous solutions.

ground machines must be without delay dislocated on another major activity (another building project). This situation causes slippage of dates within the range of 21 days. After that period ground works could be resumed.

This specific condition is the cause of heterogeneous solution of the simulation. It is difficult to find the solution of this building project by using standard statistical methods. It is convenient to take advantage of visualization techniques and particular simulation calculations.

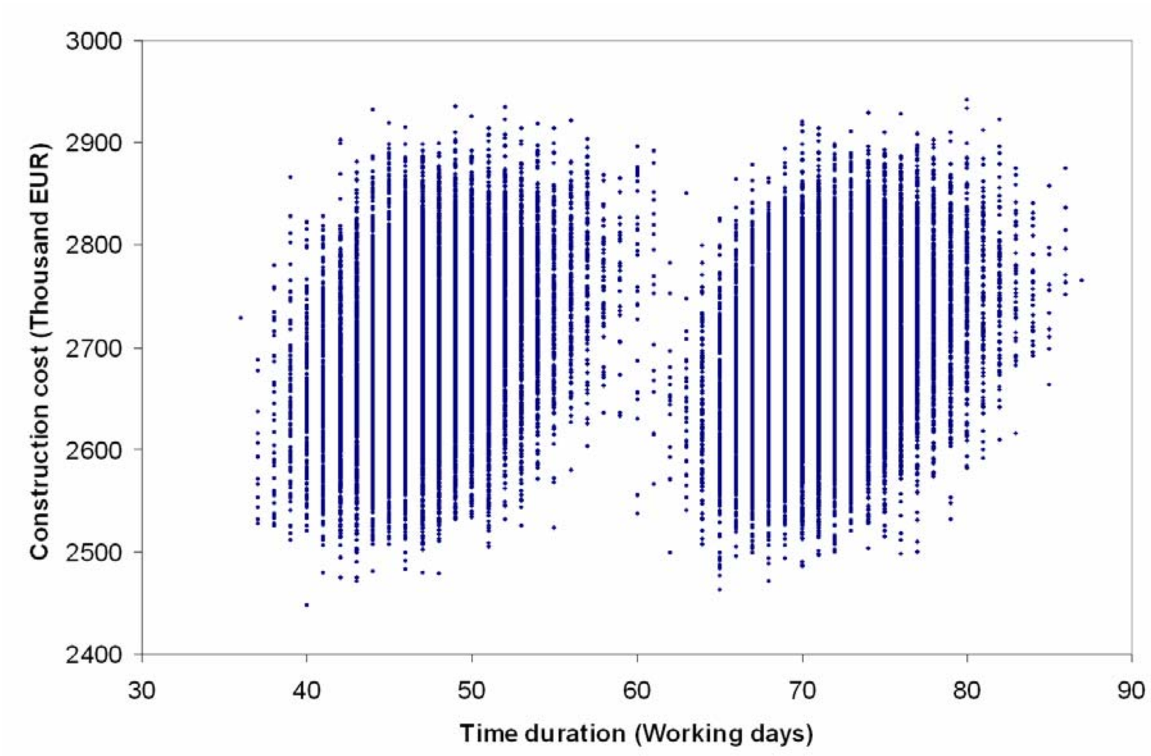


Fig. 6a Example of graph with interdependences among time duration and construction cost.

Important information regarding the proposal of a future project time schedule is specified by tests of potential scenarios of the project development with current fixing of certain parameters of the building organizational model. It is possible to obtain important information about critical parameters of the planned project, for example by fixing of deviations work of scope of work of particular activities see ***Q*** in notation (1)**.**

It is common practice to present the probability of the total construction time of a building project without a cost viewpoint (Fig. 5). A better expressed project cost is presented as a respected fixed value that will be stable and independent of project duration. Addressing this notion the proposed approach of simulation of interrelated values *time* and *cost* in Fig. 4 is more comprehensible and complex as information in Fig. 5 where

$$\sum_{T} \mathbf{P}(a \leq T \leq b) = F(t_b) - F(t_a) \tag{3}$$

or as for calculation with fixed scope of work

$$\sum_{T} \mathbf{P}(45 \leq T \leq 89) = \mathbf{P}(sim\boldsymbol{TAB}_{\text{project}}(T)) \tag{3a}$$

A similar situation develops if we fix alternation of time schedules for the project. Scope of work given as C is specified as

$$\sum_{C} \mathbf{P}(x \leq C \leq y) = F(c_y) - F(c_x) \tag{3b}$$

for data simulated in Tab. 3 we display in Figure 6.

$\sum_{C}$ $\mathbf{P}(2411 \leq C \leq 3131) = \mathbf{P}(simTAB_{\text{project}}(C))$, for calculation with fixed time ration (3c).

In Fig. 6 we may follow changes of project cost for fixed on duration of observed project.

The expected time duration of total construction project is given by its mean value

$$\mathbf{E}[T_{project} \mid C = \text{const.}] = \sum_{T} t_i \; P(T = t_i) = \bar{t} \tag{4}$$

Accordingly it is possible to quantify expected scope of work of total construction project by its mean value

$$\mathbf{E}[C_{project} \mid T = \text{const.}] = \sum_{C} c_i \; P(C = c_i) = \bar{c} \tag{5}$$

6 THE SEARCH FOR RELIABLE CONSTRUCTION COST AND TIME DURATION

The simulation model is able to calculate, on the basis of input level of probability, the adequate construction cost and time duration of a project. The reciprocal view attends to finding out the adequate level of probability for construction cost and activity durations.

There are two ways that lead to the calculation of adequate level of probability. The first way consists in fixation of one variable parameter and investigation of changes in remaining parameter. The second way consists in simultaneous investigation of deviations of both parameters.

The approach used in this paper is based on expression (1) and Table 4 (discreet probability density table) enables on data of Table 3 calculate the level of probability as cumulative density function

$$F(T; C) = \sum_{T} \sum_{C} \mathrm{P}(T = t_i; C = c_i) \qquad (6),$$

where t_i a c_i runs through the set of all possible values of T and C and

$$\sum_{T} \sum_{C} \mathrm{P}(T = t_i; C = c_i) = 1 \qquad (6a).$$

The Fig. 6b shows extracted data from expression (6) or Table 4 as histogram.

On closer investigation of results of particular simulations there was found a dependence between level of probability and construction cost and time duration. In the following figures are shown bilateral interactions of mentioned project parameters.

Tab. 4 Example of calculation of level of Discrete Probability Distribution (DPD).

Classes	Scope of work (Thousand EUR)																																				Total
Time duration (day)	2411	2431	2451	2471	2491	2511	2531	2551	2571	2591	2611	2631	2651	2671	2691	2711	2731	2751	2771	2791	2811	2831	2851	2871	2891	2911	2931	2951	2971	2991	3011	3031	3051	3071	3091	3111	3131	
45					1			1						1			1			1																		5
47					2	4	1	1	5	1	2	1	1	2	2	1	1							2														26
49		1	2	4	6	10	6	14	17	17	19	19	25	18	20	21	14	8	13	7	5	5	3	2	1	1												258
51	1	3	5	8	19	23	33	42	42	68	68	71	74	69	81	67	41	54	60	30	31	19	10	7	9	2		1	2									940
53	2	3	6	10	24	41	64	81	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	158	145	122	94	113	84	86	56	43	30	16	8	8		2		1						2 270
55	1	5	2	13	34	53	77	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	307	287	267	253	205	177	127	127	75	56	34	23	10	6	5			2				4 386
57	1		8	20	26	63	87	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	478	477	458	383	341	286	263	[illegible]	141	111	87	52	26	23	9	3	2	1				6 457
59		1	2	12	28	46	87	110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	480	535	543	552	542	469	402	397	351	294	250	174	129	92	58	31	17	10	6	2	1			7 516
61			4	9	21	33	50	98	140	212	257	313	319	410	491	514	485	522	515	520	480	434	382	298	252	197	141	87	60	28	22	10	3	1	2			7 310
63		1	1	8	10	23	47	56	93	137	178	230	279	355	378	465	447	445	462	480	415	383	348	315	278	228	170	112	83	53	32	15	2	2			1	6 532
65		1		6	8	10	22	40	56	106	137	130	210	259	251	308	341	364	351	374	353	334	290	277	245	168	154	97	65	41	22	13	12	3	1			5 049
67			1	3	3	4	12	20	32	58	69	97	155	139	194	224	219	233	270	304	262	255	232	208	169	161	106	83	51	29	25	11	5	2	1			3 637
69			1	2	1	2	6	7	22	34	39	62	74	96	106	114	156	170	171	179	181	169	186	158	115	107	96	52	54	31	23	8	3	2	1			2 428
71						2	2	6	4	17	13	25	24	44	52	74	81	101	119	113	118	127	104	115	91	84	58	54	29	22	12	5	6	2	3			1 507
73							1	4	1	7	9	13	24	23	29	37	36	59	70	50	70	65	60	65	49	53	34	35	22	16	13	3	2	2				852
75									1	2	2	2	7	11	14	12	20	25	25	33	39	36	38	44	32	28	29	20	8	11	2	1						442
77							1		2		1	1	1	5	4	5	6	16	14	13	15	12	17	23	14	15	11	11	14	5	1	5		1				213
79											1			2	1	1	7	2	5	5	5	9	10	6	7	12	8	4	3	5	5	3		1				102
81															2	1	1	1	2	4	2	4	2	4	5	3	9	3	2	2	1		2	1			1	52
83																		1	3				1	1	1		1	2			1							11
85																					1			2				2			1							6
87																																						0
89																												1										1
Total	5	15	32	95	183	314	496	701	989	1 483	1 752	2 082	2 480	2 800	3 082	3 327	3 329	3 439	3 441	3 331	3 009	2 798	2 480	2 196	1 764	1 416	1 075	739	487	305	191	88	43	22	9	0	2	50 000

Level of probability: 0,7476

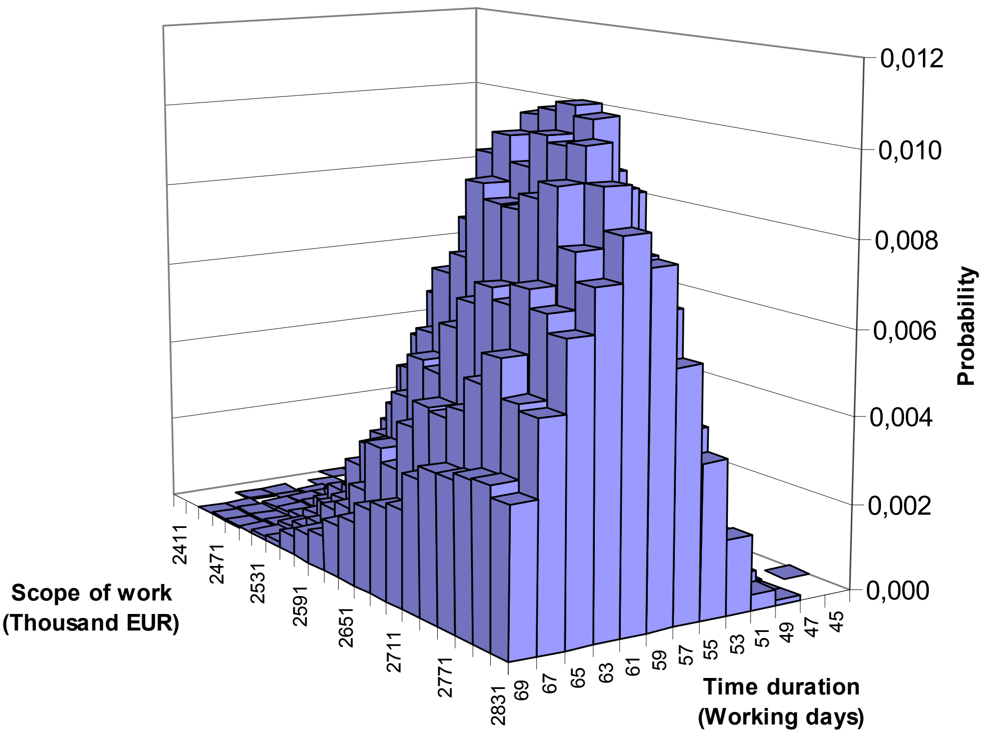


Fig. 6b Bar chart 3D for DPD on level of probability $F(T;\ C) = 0{,}7476$.

7 PRESUMED DYNAMIC PROGRESS CHART

Among interpretive outputs of the application software belongs the compilation of a presumed dynamic progress chart. This progress chart represents the expected scenario of development of a building project with the mapping of potential time dislocations for particular activities. The calculation of a presumed dynamic progress chart is based on an algorithm, which calculates mean values as a partial result of the simulated building project.

Tab. 5 Presumed dynamic progress chart of building project.

Activity	Scope of work	Production speed	Time duration	Start	End	Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ground works	182	35	6	2	7		35	35	35	35	35	9,5																		
Water connection	226	21	11	9	19									21	21	21	21	21	21	21	21	21	21	15						
Sewerage connection	190	54	3	10	12										54	65	71													
Electricity connection	104	94	2	22	23																						94	9,7		
Bottom construction	536	39	11	13	23													39	41	43	45	48	50	53	55	58	61	42		
Dumping place	55	50	2	4	5				50	5																				
Overhead construction	943	38	17	25	41																									38
Roof	338	43	7	43	49																									
Inside parget	60	31	3	51	53																									
Facade rendering	72	31	3	54	56																									
Completing works	53	8	7	54	60																									
Demands of sources through time Q'(t)						0	35	35	85	40	35	10	0	21	75	86	92	60	62	64	67	69	71	68	55	58	155	52	0	38
Total demands of sources through time Q(t)						0	35	69	154	193	228	237	237	258	333	419	511	571	634	698	765	833	905	972	1 027	1 085	1 240	1 292	1 292	1 331

Key:

… Noncritical activity
… Critical activity
… Total reserve
… Waiting for activity
… Waiting for activity - on critical way
… Possible progression of activity

The progress charts of building project are based on calculation of mean values of start and end of project activities $\mathbf{E}(T; C) = \mathbf{E}(45 \le T \le 89; 2411 \le C \le 3131)$. However the information of start-risk and end-risk represents substantial information calculated as following variances

$$D(T) = k_{tt} = \sigma_t^2 = \sum_T (t_i - \bar{t})^2 P(T = t_i) \tag{7}$$

where k_{tt} is correlation index,

$$D(C) = k_{cc} = \sigma_c^2 = \sum_C (c_i - \bar{c})^2 P(C = c_i) \tag{8}$$

where k_{cc} is correlation index. Further the correlation index k_{tc} is generally given as

$$|k_{ij}| = \begin{vmatrix} k_{11} & k_{12} & k_{13} & k_{1n} \\ k_{21} & k_{22} & k_{23} & k_{2n} \\ k_{31} & k_{32} & k_{33} & k_{3n} \\ k_{n1} & k_{n2} & k_{n3} & k_{nn} \end{vmatrix} \qquad \text{when } k_{ij} = k_{ji} \tag{9}$$

For our example the correlation index k_{tc} is given as

$$\left|k_{tc}\right| = \begin{vmatrix} k_{tt} & k_{tc} \\ k_{ct} & k_{cc} \end{vmatrix} = \begin{vmatrix} 1 & 0{,}2 \\ 0{,}2 & 1 \end{vmatrix} \tag{10}$$

In the Tab. 5 are characteristics of dispersion interrelated to chart activities. More extensive explanations are given in Figure 5a.

Tab. 5a Presumed dynamic progress chart of building project.

The earliest possible start term of the project $t_1 = 1$

The probable start term of the project $t_1 = 2$

The probable end term of the first activity $t_1 = 7$

The latest possible end term of the first activity $t_1 = 14$

The mean value of the sixth activity $\mathbf{E}(; C) = \mathbf{E}(2; 55)$

Activity	Scope of work	Production speed	Time duration	Start	End	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Ground works	182	35	6	2	7		35	35	35	35	35	9,5																		
Water connection	226	21	11	9	19									21	21	21	21	21	[illegible]	21	21	21	21	15						
Sewerage connection	190	54	3	10	12										54	65	71													
Electricity connection	104	94	2	22	23																									
Bottom construction	536	39	11	13	23																									
Dumping place	55	50	2	4	5				50	5																				
Overhead construction	943	38	17	25	41																									38
Roof	338	43	7	43	49																									
Inside parget	60	31	3	51																										
Facade rendering	72	31	3	54																										
Completing works	53	8	7	54																										
Demands of sources through time Q'(t)						0	35	35	85	40	35	10	0	21	75	86	92	60	62	64	67	69	71	68	55	58	155	52	0	38
Total demands of sources through time Q(t)						0	35	69	154	193	228	237	237	258	333	419	511	571	634	698	765	833	905	972	1 027	1 085	1 240	1 292	1 292	1 331

There are extensive possibilities of calculation of correlations of T and C calculated as normalized values as

$$r_{ij} = \frac{k_{ij}}{\sqrt{D[T_i]D[C_j]}} \tag{11}$$

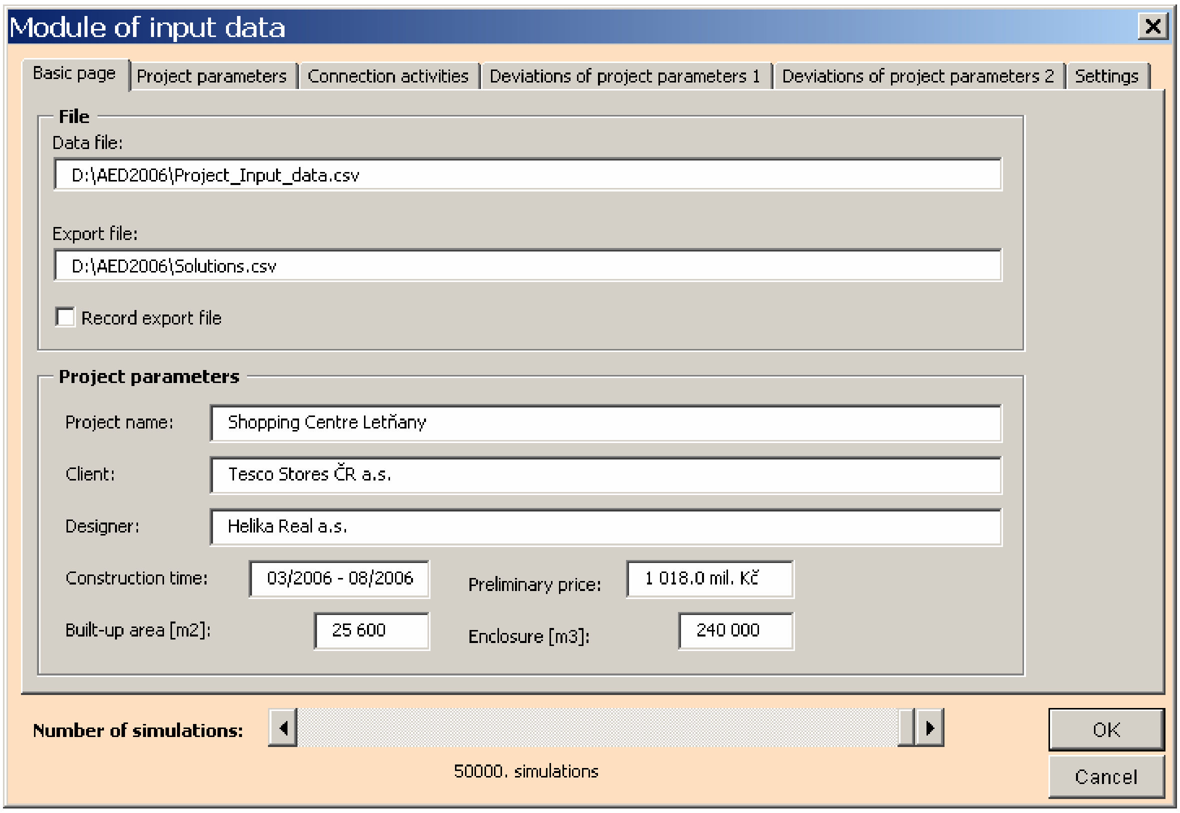
8 SOFTWARE SUPPORT

Tab. 6 – 10 shows example of Module of input data . *The Basic page, Project parameters, Connection activities, Deviations of project parameters.*

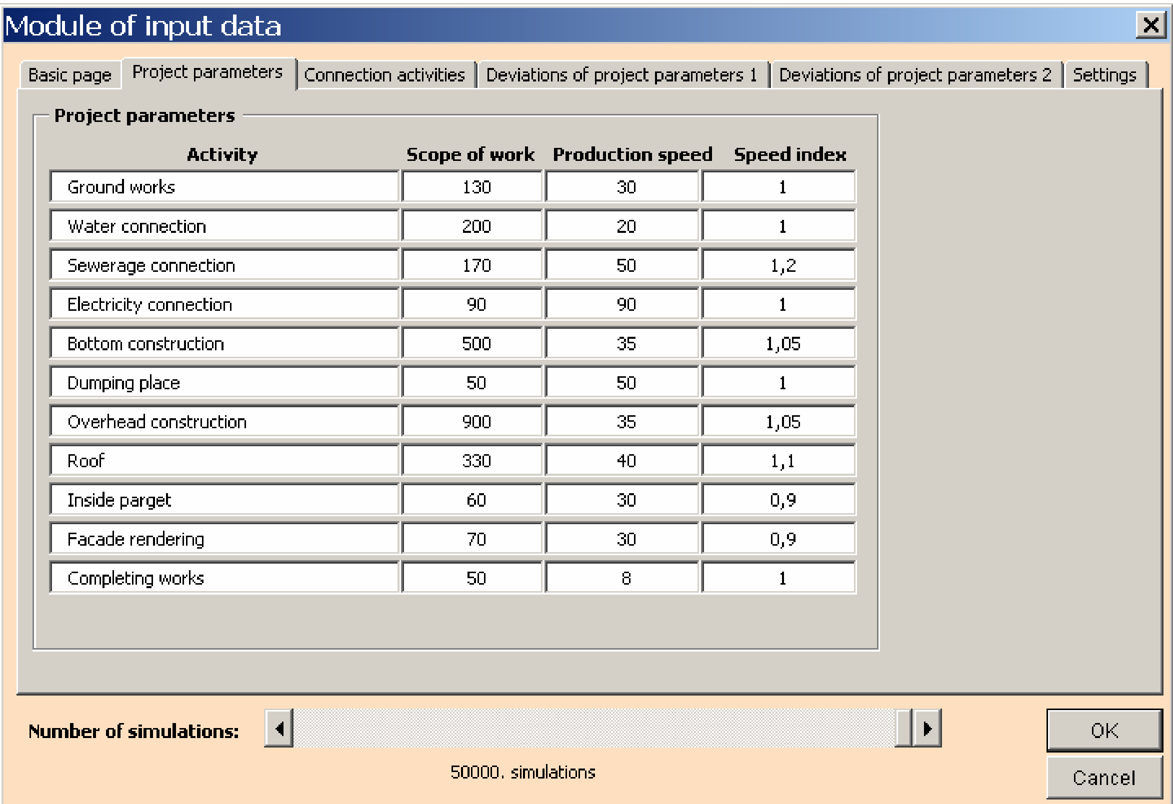
9 CONCLUSION

This model makes it possible to predict an expected project cost and duration schedule depending on input parameters such as production speed, scope of work, time schedule, bonding conditions, maximum and minimum deviations from scope of work and production speed. The useful results are risk evaluation for the projects or for the project activities.

Tab. 6 Module of input data – *Basic page*



Tab. 7 Module of input data - *Project parameters*



Activity	Scope of work	Production speed	Speed index
Ground works	130	30	1
Water connection	200	20	1
Sewerage connection	170	50	1,2
Electricity connection	90	90	1
Bottom construction	500	35	1,05
Dumping place	50	50	1
Overhead construction	900	35	1,05
Roof	330	40	1,1
Inside parget	60	30	0,9
Facade rendering	70	30	0,9
Completing works	50	8	1

Tab. 8 Module of input data - *Connection activities*

Module of input data

Basic page | Project parameters | Connection activities | Deviations of project parameters 1 | Deviations of project parameters 2 | Settings

Activity	with connection to			with connection to			with connection to			with connection to			with connection to		
	Activity	Type	ε	Activity	Type	ε	Activity	Type	ε	Activity	Type	ε	Activity	Type	ε
1. Ground works															
2. Water connection	1	0													
3. Sewerage connection	1	0													
4. Electricity connection	2	0		3	0										
5. Bottom construction	3	0													
6. Dumping place	1	1	1												
7. Overhead construction	4	0		5	0		6	0							
8. Roof	7	0													
9. Inside parget	8	0													
10. Facade rendering	9	0													
11. Completing works	9	0		10	2										

Note: Type of bonding condition: 0 = End - Start, 1 = Start - Start, 2 = End - End.

Number of simulations: 50000. simulations

OK | Cancel

Tab. 9 Module of input data - Deviations of project parameters

Module of input data

Basic page | Project parameters | Connection activities | Deviations of project parameters 1 | Deviations of project parameters 2 | Settings

Activity	Deviation of scope of work		Deviation of production speed	
	Minimum	Maximum	Minimum	Maximum
Ground works	-0,1	0,9	-0,2	0,5
Water connection	-0,05	0,3	-0,1	0,2
Sewerage connection	-0,1	0,35	-0,15	0,3
Electricity connection	-0,1	0,35	-0,1	0,2
Bottom construction	-0,1	0,25	-0,15	0,4
Dumping place	-0,15	0,3	0	0
Overhead construction	-0,1	0,2	-0,1	0,3
Roof	-0,1	0,15	-0,05	0,2
Inside parget	-0,1	0,1	-0,05	0,1
Facade rendering	-0,1	0,15	-0,05	0,15
Completing works	-0,2	0,3	-0,15	0,25

Number of simulations: 50000. simulations

OK | Cancel

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