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CONSTRUCTION SPEED AND CASH FLOW OPTIMISATION

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Abstract. *Practical examples show that the improvement in cost flow and total amount of money spend in construction and further use may be cut significantly. The calculation is based on spreadsheets calculation, very easy to develop on most PC´s now a days. Construction works, are a field where the evaluation of Cash Flow can be and should be applied. Decisions about cash flow in construction are decisions with long-term impact and long-term memory. Mistakes from the distant past have a massive impact on situations in the present and into the far economic future of economic activities. Two approaches exist. The Just-in-Time (JIT) approach and life cycle costs (LCC) approach.*

The calculation example shows the dynamic results for the production speed in opposition to stable flow of production in duration of activities. More sophisticated rescheduling in optimal solution might bring in return extra profit.

In the technologies and organizational processes for industrial buildings, railways and road reconstruction, public utilities and housing developments there are assembly procedures that are very appropriate for the given purpose, complicated research-, development-, innovation-projects are all very good aspects of these kinds of applications. The investors of large investments and all public invested money may be spent more efficiently if an optimisation speed-strategy can be calculated.

1 INTRODUCTION

Organising construction activities according to the latest possible internal time schedule, is called the Just-in-Time method (JIT). This method has never been consistently applied in large construction projects, though this paper will argue that it should be. Time dependent (sequencing) processes in construction production are an appropriate place for practicing JIT methods and cut future life cost of LC.

2 ECONOMIC MOTIVATION

From the modern construction point of view, early completion may not be either necessary or economically useful. However, the idea that *what is completed can be counted on,* has extraordinary strength in some areas of the construction industry, investments and other project with a long life cycle (LLC). The efforts of many contract managers to create a time reserve and to lower the risk of breaching the construction deadline go so far as to perform a series of works earlier than is technically and organizationally necessary.

3 DYNAMIC PROCESS SCHEDULE

It is possible to get the calculation of activities duration (partial jobs) by spreadsheet calculation (see fig. 1). It is reasonable to calculate activity duration, cash flows and simulation of risks, if some activities are risk conditioned. We may see the spreadsheet table not only as a tool for calculation but also as an expression of complex formulae [2], [3]. This approach may offer a mechanism for answers to the *sensitivity of manageable parameters* (say costs, construction speeds; *Duration* of activity *i* (job) will be calculated as *Costs*(*i*)/*Production Speed*(*i*), or $D_i = c_i/v_i$.). We scrutinize the spreadsheet not only as a matrix or as a table. $\mathbf{TAB}_{\text{project}}$ is a complex description of project conditions that enables calculations, simulations, and parameterizations for the evaluation of potential management changes. We may describe [6] a project as a table structure

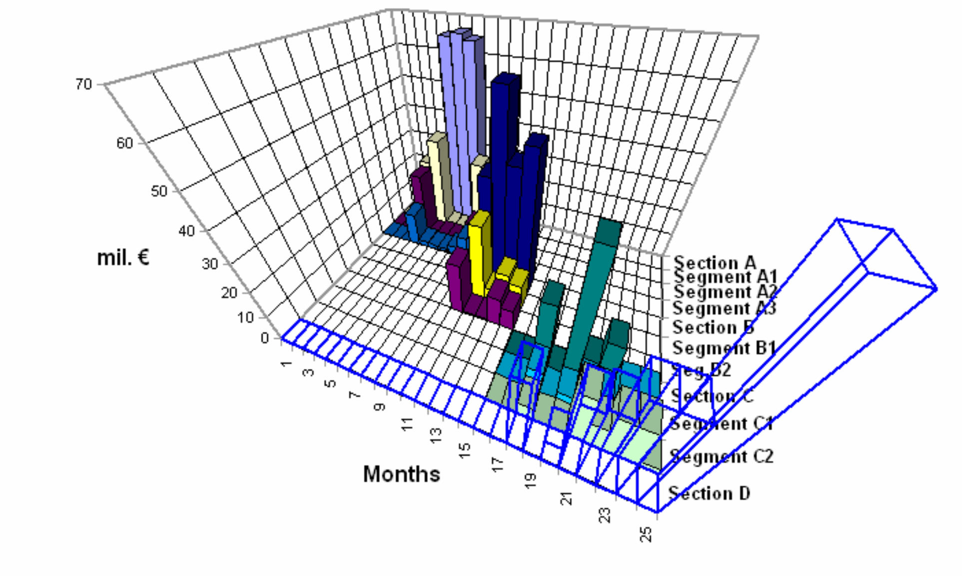
$$\mathbf{TAB}_{project} = \boldsymbol{N}\left[\boldsymbol{D} = f(\boldsymbol{Q},\ \boldsymbol{v}),\ \therefore Org\right] \quad (1)$$

based on a *network* composition (***N***) of duration sets of partial activities ***D,*** quantities (costs, production volumes) ***Q*** given predominantly as costs and production speeds ***v***. Further there are specified organisational compositions (mark $\therefore$) among activities, $\therefore\boldsymbol{Org}$. The set of activity

compositions given as $\therefore\boldsymbol{D}_{network}$ play the role in quantification of durations ***D*** (let us say technological connections of activities such as *Start-Start, End-Start, End-End*; combined connections like the *critical activity* approach, *Minima condition*, *Maxima condition*, and other logical connections of type *If-Then*). The conditioning in costs and other mostly legal conditions and regulations are even more sophisticated $\therefore\boldsymbol{D}$ or $\therefore\boldsymbol{Org}$ conditions in progress. We may write a more extensive notation (2) for this purpose as

$$\mathbf{TAB}_{project} = \boldsymbol{N}\left[\boldsymbol{D} = f(\boldsymbol{Q},\ \boldsymbol{v},\ \therefore\boldsymbol{D}_{network}),\ \therefore\boldsymbol{Org}\right] \quad (2)$$

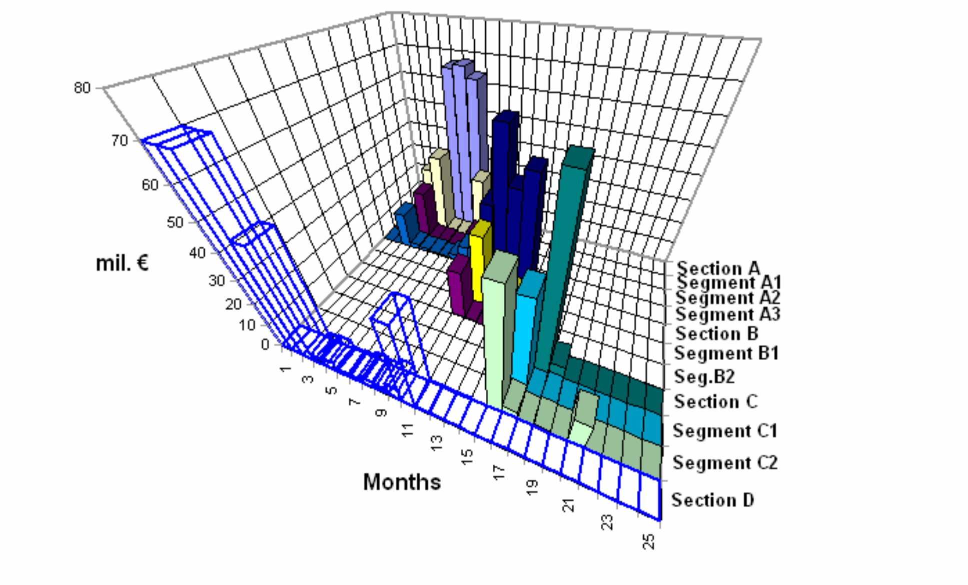
Nevertheless the comprehensive open approach emphasized in this paper is based on *spreadsheets* [6], enabling the calculation of time and costs and furthermore conditioned calculations of *risks* (3).



Total
Q
300
100
50
40
200
70
40
100
60
70
250

Total	0	0	0	70	70	70	70	70	70	70	30	70	70	70	70	0	0	70	0	60	70	70	70	70	70	1280
Time factor	1,21	1,20	1,19	1,18	1,17	1,16	1,15	1,14	1,14	1,13	1,12	1,11	1,10	1,09	1,08	1,07	1,07	1,06	1,05	1,04	1,03	1,02	1,02	1,01	1,00	1280
Recalculation	0	0	0	83	82	81	81	80	79	79	34	78	77	76	76	0	0	74	0	62	72	72	71	71	70	1397,758
																									γ	max
																									1,1	70

Fig. 1a Input situation, time and costs layout structure *max* production speed 70 mil €, minimal total costs 1397,758 mil €.



Total
Q
300
100
50
40
200
70
40
100
60
70
250

Total	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	7,3	0	13	0	0	0	0	1280
Time factor	1,21	1,20	1,19	1,18	1,17	1,16	1,15	1,14	1,14	1,13	1,12	1,11	1,10	1,09	1,08	1,07	1,07	1,06	1,05	1,04	1,03	1,02	1,02	1,01	1,00	1280
Recalculatio	85	84	83	83	82	81	81	80	79	79	78	78	77	76	76	75	75	74	7,7	0	13	0	0	0	0	1447,047
																						γ	1,1		max	70

Fig. 1b Time and costs layout structure *max* production speed limit 70 mil. €, maximal total costs 1447,047 mil. €.

However, the application to a real building site has his price and creates some substantial profits. The extension to real practical management decisions needs further information about risk and sensitivity to proposed managerial changes. The concise notation of the problem is given in (3) and (3a).

$$\mathbf{TAB}_{\text{project}} = \boldsymbol{N}\left[\boldsymbol{D} = f(\,\boldsymbol{Q}|risk,\ \boldsymbol{v}|risk,\ \therefore \boldsymbol{D}_{network}),\ \therefore \boldsymbol{Org}|risk\right] \quad (3)$$

$$\mathbf{TAB}_{\text{project}} = \boldsymbol{N}\left[\boldsymbol{D} = f(\,\boldsymbol{Q}|param,\ \boldsymbol{v}|param,\ \therefore \boldsymbol{D}_{network}),\ \therefore \boldsymbol{Org}|param\right] \quad (3a).$$

The parameterization (3a) paves the way to limits for management intentions and economic reasoning [6].

4 THE OPTIMISATION PROBLEM

Let us direct our attention to a substantial economic problem. How can the possible effects of optimisation of construction cycle and later on maintenance and renovation cycles be applied to the construction industry and investment strategies?

The construction understood as an organisational and technological procedure $\therefore \boldsymbol{Org}$ is described by a spreadsheet driven table. The practical example presented in the time schedule is the scope of fig. 1a. The scheme of construction process is divided into three main activities or sections (A, B, C, D) and their parallel work-subgroup segments. The technology of production progress has its main parts A, B, C sequenced in time. The structure of fig. 1a is result of costs optimisation layout structure for *max* production speed 70 mil €/months and minimal total construction project costs are 1397,758 mil €. The optimal solution (optimal production speeds) for earliest possible layout has the total costs 1447,047 mil. € (see fig. 1b).

The calculation of fig. 1a and 1b shows the dynamic results for the production speed in opposition to stable flow of production in duration of activities. More sophisticated rescheduling in optimal solution might bring in return extra profit.

The risk analysis calculation is usually a subsequent supporting calculation. The evaluation of *potential management decisions* provided by the feasibility of parameterisation may be a further step. The evaluation of time and cost feasibility in terms of management decisions creates new limits and probable new safer horizons in decision-making.

In fig. 2 we may follow limit-result of a policy of earliest possible start and finish of any activity. The *total costs* of project (without time factor) are given by 1280 t. €. The sum of cash flow fixed in time is given as 600 t. €, that indicates total volume might be shifted in time (see also fig. 2). This indicates a relative space for *shifts* in construction *capacity cost flow by optimisation*.

For the bank loan rate and project risk gives for expample i = 0,17. The value of construction money during 25 months of construction time increases. There are many ways how to recalculate cost to the future costs. In the example given in the fig. 1a and 1b we use a recalculation of production speeds $Q'(t)$ by means of power function γ^{t}, *where* $\gamma = 1{,}17$, $\gamma = 1/(1+i)$, see expression (5). The present value of total production speed $Q_{PV}'(t)$ is given as

$$Q_{PV}'(t) = Q'(t)\,\gamma^{t} \quad (4),$$

where time decreases from the construction start in $t = -25$ (left side of the fig. 1a) to $t = 0$ in the project finish at the right side. A similar result may be given by exact calculation used in the financial calculation as

$$Q_{PV}'(t) = Q'(t)\ 1/(1+i)^{t} \quad (5).$$

The alternative calculation by means of relation

$$Q_{PV}'(t) = Q'(t)\, e^{it} \qquad (6)$$

may offer also an acceptable solution for optimisation.

This percentage indicates the costs of *credit* of unproductive frozen investment assets. The improved technology and organization of construction schedule is, from this point of view, economically desirable and feasible.

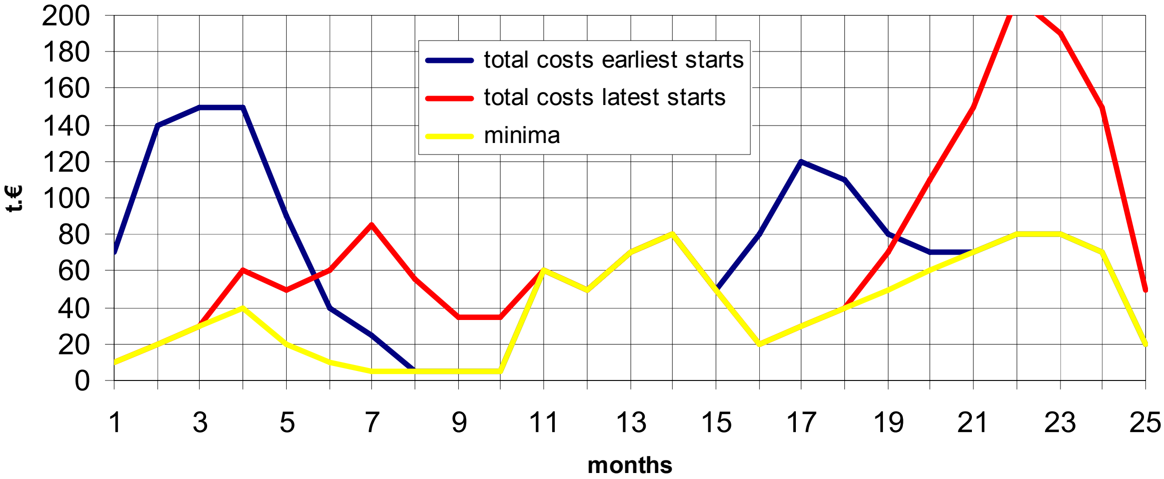


Fig. 2 Comparison of total and in time fixed costs cash flow, example.

From a mechanical point of view of possible shifts (say earliest and latest possible starts and finishes), we will get a good deal of profit. If segments (activities) A1 and A2 will slip to the time end of A section and similar segments B1, …, C1, …, D to the end of their Sections, the total latest cost flow will be gained. If we recalculate by time factor cash flow given in cash-flow for latest starts the total value of money is 1367,623 t. € (see fig.3). Moreover, if we are able to create a dynamic shape of activities, there is more space for effective rationalisation of cash flow. Optimisation may pave the way to this sophisticated efficiency. We understand it only in terms that an optimal solution is not intuitively available.

The construction of γ may differ for diverse projects. The new reasoning is given in guideline *Basel II* criteria. It usually includes (auditing to bank loan rate) *risk rate* and *entrepreneurial profit*. For a commercial case it might be compounded by components mentioned as interest rate, risk, by γ = 0,10 + 0,07. The losses from frozen capital for t=15 years raise $0{,}17^{15}$ = 2,55 times capital spent for ordinary cash flow spent in construction. In East Europe the power plants such as Transportation Networks completation in towns (München, Dresden or Prague). The *s*ituation was predetermined by low production capacity (low ability to create high construction speeds). Complicated research-, development-, innovation-projects are all very good aspects of these kinds of applications. There are also other reasons why construction management has shifted to other then economic rules. *Reliability* of finishing date will be the other reason. Generally, a fair break down of advantages and risks of the contracting and contracted subject might lead to more respectable economic situations.

The *interest rate* might lead us to question the robustness of this constant. However, it is not the interest that moves optimisation model forward, but the limit of cash flow proposed for different activities. The time we have for construction is not continuous time. Construction time is the discrete time linked to limited available resources.

Nevertheless, as may be shown, there is no relation between strategy (structure of construction works) and robustness of interest rate (time factor) build into optimisation. For an *optimal strategy* it is *irrelevant* how considerable the value γ really is. This value only makes bigger the penalty if management does not keep to an optimal strategy.

In the technologies and organizational processes for industrial buildings, railways and road reconstruction, public utilities and housing developments there are *assembly procedures* that are very appropriate for the given purpose, complicated research-, development-, innovation-projects are all very good aspects of these kinds of applications. The investors of large investments and all public invested money may be spent more efficiently if an optimisation speed-strategy can be calculated.

The optimal solution is in many ways surprising. See Fig. 3 and compare the results with the calculation in Fig. 1a, or 1b for earliest and latest possible execution. If we compare the results in Fig. 4 and 3 for speed limit 100 mil. € we see that the total difference between earleast schedule 1462,180 mil. € and latest schedule 1386,565 mil. € is 75,615 mil. €. The limitation of speed production on 70 mil. € /months in Fig. 1a and 1b reduce the difference to 49,289 mil. €.

Changes, using optimisation, might lead in many cases to a radical drop in the total costs. Even if no profit could be achieved in practice, there is a range of possible managerial manipulation that could, if skilfully exploited, produce cost savings.

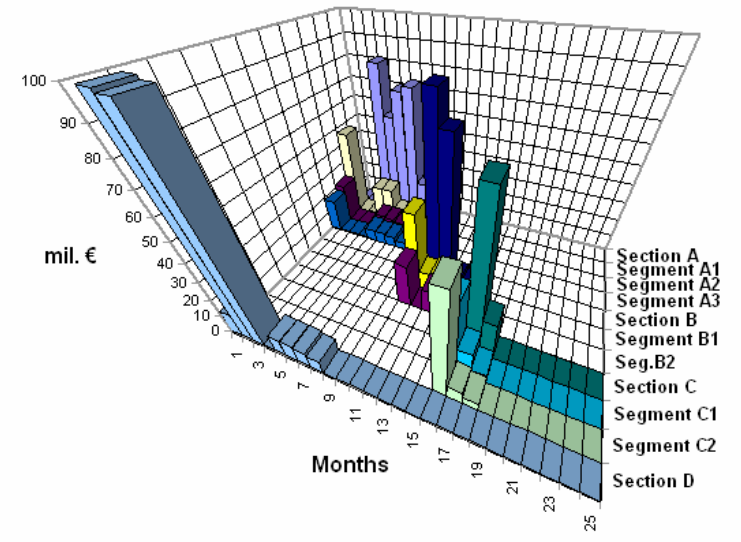
A more detailed analysis can show under what conditions production sources (production speed or cash flow to activities) can be increased.

Other scenarios could also be presented. The main outcome of the whole task is an increase in **production speeds** and a **reduction of time margins** (floats). The overall effect is in essence a change in the organisation of project completion.

5 A GENERALIZATION OF TIME DEPENDENT CAPACITY EXPANSION

The problem of optimal capacity expansion of construction work as a time dependent problem has been studied in recent years in many different applied contexts. Traditional capacity planning usually begins with a forecast of demand on the basis of organizational or technological needs. Planning and scheduling has for many years been the dominant approach in Central European management methodology. New approaches adopting a more productive methodology seem to be needed. Modern management of time dependent capacity expansion enables applications in *production planning*, *strategic planning*, *inventory control*, and *network design*. Applications to telecommunications have been published by Laguna [4].

The time dependent capacity problem consists of finding the combination of activities j ($j = 1, 2, \dots, N$) with price p_j and demand efficiency c_j, that should be employed in each time period t ($t = 1, \dots, T$).

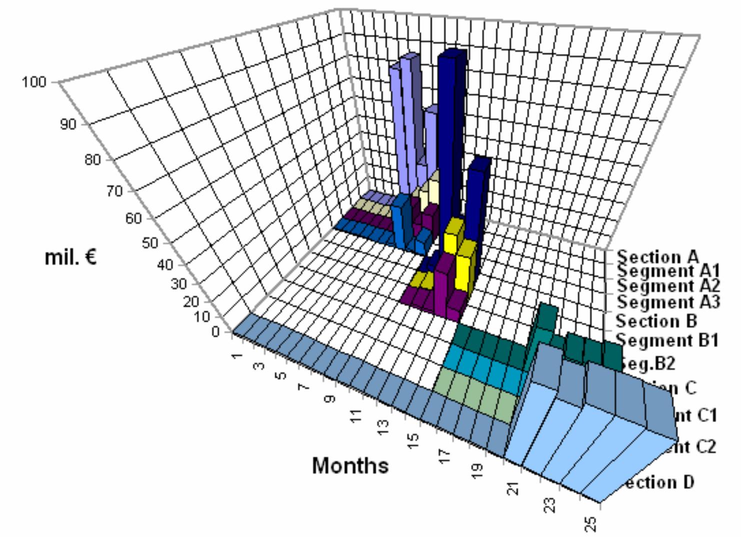


	Total
	Q
	300
	100
	50
	40
	200
	70
	40
	100
	60
	70
	250

Total	100	100	100	100	100	100	100	40	0	0	100	100	100	10	0	100	100	30	0	0	0	0	0	0	0	1280
Time factor	1,21	1,20	1,19	1,18	1,17	1,16	1,15	1,14	1,14	1,13	1,12	1,11	1,10	1,09	1,08	1,07	1,07	1,06	1,05	1,04	1,03	1,02	1,02	1,01	1,00	1280
Recalculation	121	120	119	118	117	116	115	46	0	0	112	111	110	11	0	107	107	32	0	0	0	0	0	0	0	1462,18

γ	max
1,1	100

Fig. 3 Earliest starts for production speed 100 mil. € / months, potential for time cuts 10 months.



	Total
	Q
	300
	100
	50
	40
	200
	70
	40
	100
	60
	70
	250

Total	0	0	0	0	0	90	100	100	100	100	0	10	100	100	100	0	0	0	0	0	80	100	100	100	100	1280
Time factor	1,21	1,20	1,19	1,18	1,17	1,16	1,15	1,14	1,14	1,13	1,12	1,11	1,10	1,09	1,08	1,07	1,07	1,06	1,05	1,04	1,03	1,02	1,02	1,01	1,00	1280
Recalculation	0	0	0	0	0	105	115	114	114	113	0	11	110	109	108	0	0	0	0	0	83	102	102	101	100	1386,565

γ	max
1,1	100

Fig. 4 Latest starts for production speed 100 mil. € per months, potential for time cuts 11 months.

The limitations are given by the total demand (capacity) D_t at a minimum cost.

Then, the problem becomes

$$min\sum_{t=1}^{T}\sum_{j=1}^{N} p_j \gamma^{t-1} x_{jt} \tag{7}$$

subject to

$$\sum_{t=1}^{T} \sum_{j=1}^{N} c_j x_{jt} \geq D_t \tag{8}$$

for all t where

$$x_{jt} \geq 0 \tag{9}$$

is production speed for all j and t. Further γ = 1+i enables the recalculation of production speed values on future value, by means of a discount factor (0 < i <1) for all x_{jt} for activities j in time t.

The structure of the production speed may be very variable. Table 1 shows a general example of this interpretation. Demand D_t may be structured not only as to t as a particular time period, but also to demand blocks related to different activities j and even to blocks of technologically or organizationally related activities.

Table 1 General scheme of a production structure

	t =1	t =2	t =3	…	t =T
Activity *1*	x_{11}	x_{12}	x_{13}	…	x_{1T}
Activity *2*	x_{21}	x_{22}	x_{23}	…	x_{2T}
	…	…	…	…	…
Activity *N*	x_{N1}	x_{N1}	x_{N1}	…	x_{N1}
	D_1	D_2	D_3		D_T

If the matrix of variables in time t, where t = (1, 2, 3, ..., T) is assigned for particular scenarios, where (s = 1, 2, ..., S), say as z_{ts}, the problem becomes [4]

$$\min\ F(\mathbf{x}) = \sum_{t} \sum_{j} p_j \gamma^{t-1} x_{jt} + w\rho(\pi_s, z_{ts}) \tag{10}$$

subject to

$$\sum_{t} \sum_{j} c_j x_{jt} + z_{ts} \geq D_{ts} \qquad \forall t, s, \tag{11}$$

$$x_{jt} \in (0,\ 1,\ 2, ...) \qquad \forall j, t, \tag{12}$$

$$z_{ts} \geq 0 \qquad \forall t, s, \tag{13}$$

where w is the weighting factor and ρ is the function of negative demand consequences related to the unmet demand z_{jt} and probability π_s in the range of scenarios s.

Demand D_{ts} will be presented with an uncertainty component z_{jt}, see (11). This represents an imaginary demand associated with the risk of shortage of capacity with a probability π_s related to scenario s at each period t. Function ρ may take many forms. It usually reflects the risk attitude of the decision maker. The risk may be associated with the probability of shortage of capacity, the risk of extra costs or the risk of lack of quality if the production speed exceeds certain limits. Further applications and interpretations are possible.

6 MODEL CONSTRUCTION – FURTHER GENERALIZATION

An interesting question is how far an optimal solution is dependent on production speed and what may be the optimal construction *duration* of an investment project. Let the production speed be seen as a given limit for construction of demands D_t .

$$\sum_{t=1}^{T} \sum_{j=1}^{N} c_j x_{jt} \geq D_t \tag{14}$$

The optimisation function remains in the shape given in the function (8). However the main constraint is given by maximum possible speed, that is a modification of the equation (14). Table 3 shows the optimisation result.

Table 2. Production speed and minimal costs for i = 0,10

Total Q´ max	Optimal solution earliest	Optimal solution latest
t. €	t. €	t. €
300	1 483,27	1 370,85
200	1 477,96	1 374,87
100	1 462,18	1 386,56
90	1 458,62	1 393,85
80	1 454,34	1 397,52
70	1 447,05	1 397,76
63	1 411,49	1 411,49

As Table 2 indicates there is a strong dependence between *production speed* and the costs of projects. Higher production speed means lower costs. More illustrative are data in Fig. 5.

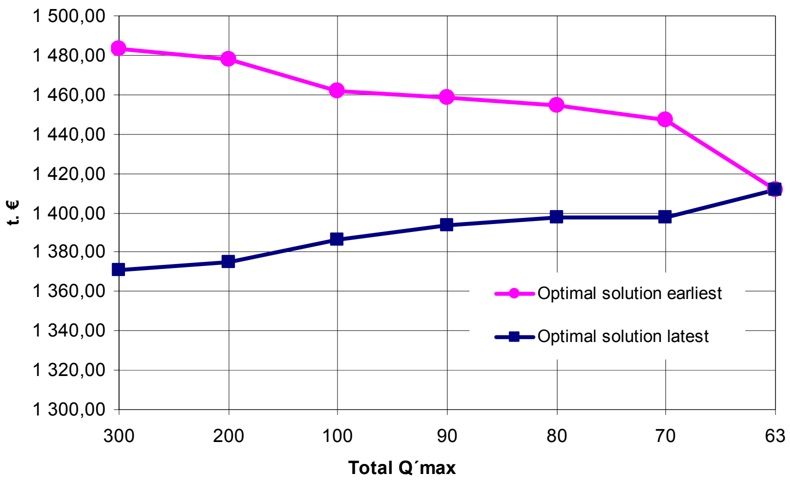


Fig. 5 Dependence of optimal solution and total Q´max.

Total cost of projects grows in correlation with the rate of exploited production speed.

What is more interesting is the structure of activities. According to production speed, the time and cash flow structure of construction work changes.

It is interesting, that the structure of activities will not change if we increase economic pressure by means of interest rate γ^t. There are professional discussions about the level of interest rate that would be necessary or needed for the development of an economic calculation (in terms of efficiency and decision-making). In our case we are looking for an optimal duration and optimal cash flow schedule of construction work. The level of interest rate is irrelevant if only $\gamma > 0$.

CONCLUSION

The implementation of a technical project carried out in conditions of high production speeds and low time reserves requires changed technologies, organization and preparation of construction. In each specific case, a civil engineer needs to know the economic impacts (the capability of applicable calculations). The next important factor in the preparation and choice of management and organisation is the ability to calculate the risks inherent in the chosen technology [1],[2],[3]. It is obvious from the given illustrative example, which has the same features as the execution of a series of construction projects in recent years, that the myth of the importance of executing works in large volumes ahead of the deadlines has significant financial consequences. The interest rate applied here (10%) is not relevant for existing commercial conditions, but there is no ultimate dependence of structure and the corresponding IR.

It is very probable that wherever construction work has to be, or was, carried out at a loss or at a low profit, bad time management and cash flow scheduling play a significant role in the economic results.

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