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LOGISTICS FOR THE SHELL CONSTRUCTION PHASE – CALCULATION OF THE NUMBER OF TRANSPORTS FOR RE-INFORCED CONCRETE WORKS USING THE MONTE-CARLO METHOD

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ABSTRACT
Construction logistics can be divided into the procurement, production and disposal logistics components. Depending on the location of the construction site, the area of construction logistics is of paramount importance with respect to an effective and efficient utilization of the production factors. Both construction method and project type have a major influence on the overall number of transports, and construction time has an impact on transport frequency. Only a small number of construction trades are involved in the shell construction phase. Upon the commencement of the finishing and technical installation stages, however, more than 50 trades may carry out work simultaneously in complex building projects. Short construction times result in more demanding requirements on logistics; the transport frequency and degree of simultaneity of transports carried out by various trades increase. This paper outlines the calculation of the number of transports for the shell construction phase whilst considering key construction management parameters. Beyond a simple, deterministic method, other options for calculation are presented that rely on the application of probability calculus.
The deterministic method results in one value per each calculation process (calculation mode 1). In calculation mode 2, probability calculus is applied in a simple way. Both range and probability of occurrence can be considered for the relevant input variables.
For the third calculation mode, the Monte-Carlo method is applied using the @RISK software. For this purpose, a distribution function is allocated to selected parameters within the calculation model. The values for the range are selected on the basis of construction management and specific structural boundary conditions. This method shows a probability distribution for each of the parameters to be determined. Using a building construction project, the application of the Monte-Carlo method to determine the number of transports is demonstrated.
The field of procurement logistics primarily deals with the supply of equipment and materials to the construction site. As part of the production logistics system, all vertical and horizontal transport processes on the construction site are planned, organized, controlled and managed. The application of logistics component is concerned with the planning, organization and management of the removal of equipment, materials and waste from the site.
Depending on the project phase, construction logistics can also be divided into a preliminary and detailed planning stage.

1. SITUATION ANALYSIS AND OBJECTIVE

To calculate the total number of transports, for earthwork more accurate calculation equations are available. Based on the technical effective output of the excavation equipments and the capacity of transport vehicles, the number of transports can be calculated with acceptable accuracy. Prerequisite for an accurate calculation are the knowledge of the swell factor and the dimensions of the excavation pit. The fixed volume of the excavated material depends on the building floor plan and the execution of the excavation pit (sloped or vertical).

The accuracy of the data for the materials and dimensions will be significantly influenced by the considered project phase. The more increasing of detailing, the more accuracy of the input parameters for the calculation of e.g. the number of transports or the transportation density we have. A degree of uncertainty there will be also in the highest degree of detailing.

Logistical considerations are also to be considered in the determination of the construction period. Based on the construction and site boundary conditions, limits for the shortest construction period may result due to logistical constraints. The limitation may follow e.g. from the maximum tolerable traffic due to the predicted traffic situation (e.g. more than 10 transports per hour are not realistically possible).

The aim of the paper is to present and to explain the deterministic calculation of the number of transports for construction projects. Furthermore, the application of the Monte-Carlo simulation for the calculation of transport will be illustrated and by using a hig h-rise building project will be presented. For the input parameters in the calculation ranges are given.

2. INFLUENCES ON THE PROCUREMENT LOGISTICS

The procurement logistics are essentially affected by the daily working hours, transport intensity, the number of transports, the type of transportation, the degree of organization and the obstacles. The number of transports mainly depends on the type of the construction, the construction dimensions and the construction method. Those means of transportation, which can be used, are determined mainly from the location and the development of the construction site.

The degree of organization influences the procurement logistics with regard to the time dependant and spatial sequence of transportation during construction. For large construction projects, when the logistics processes are centrally planned, controlled and monitored, faults can be prevented rather than with individual trades through the decentralized logistics. Thereby the losses in the productivity during construction can be avoided or reduced.

If logistical considerations by the individual executor are neglected, saving potentials can not be utilized (for example, by reducing waiting times, obstacles, etc.).

The construction period has also an impact on the procurement logistics. The transportation intensity is affected by the short time available and the possible planning interval for daily transportation. If the client sets for any construction project too short construction period, this construction period can be held by using a higher potentials, but conditional on calculated losses of the productivity (e.g. from an inefficient construction progress and inefficient logistics) would lead to higher unit prices for the executed activities. Ideally, the client has an approximate knowledge of these boundary conditions and takes into consideration these essential constructional parameters by fixation of the contractually obligatory construction period.

In high rise building projects are the most transports in the field of shell construction for the reinforced concrete works. Be used as raft foundations, depending on the floor plan dimensions and the height of the building - the most of the transports will be for these structural elements.

To calculate the number of transports per unit of time, the number of transports for the construction period and the available hours for the transportation should be determined in advance.

3. Principles for calculating the total number of transports

The number of transports can be determined for example by estimating with coefficients from similar past projects. For the detailed planning, the specific activities are considered separately. The deepness of the consideration can be up to the analysis of the transports for every construction phases. Regarding the timing of transportation, it can be differentiated between stock transports and just-in-time transports. Typical just-in-time transports are concrete transport.

Among the transports for storing are e.g. the supplies of aggregates, cement and bricks, which are kept in stores. The handling time of the transports also depends on the chosen construction method.

Depending on the deepness of consideration for the procurement logistics is to differentiate between rough and detailed planning. The validity and accuracy of the calculated values increases with increasing project knowledge and deepness of consideration.

3.1 ROUGH PLANNING

By eq. 1 with the averages for the gross cubic content of the building GCC_{BD} [m³] and performance DO_{GCC} [m³/d] the duration D_{GCC} [d] calculated.

$$D_{GCC} = \frac{GCC_{BD}}{DO_{BD}} \qquad (1)$$

The duration is needed if statements are to be made to transportation intensity. For example in the raft foundation, if the average transportation intensity is calculated, the result follows from the number of transports and duration of the reinforced concrete works for the construction element. For the detailed planning, the working days will be considered in detail and the intensity per hour of work will be analyzed (see [2]).

With eq. 2, the number of transports can be calculated based on the gross cubic content of the building $NUM_{TP,BD,GCC}$ [-]. By multiplying the rate of transportation $tp_{r,bd}$ [1/m³] with the total gross cubic content of the building GCC_{BD} [m³] we get the value for the total number of transports.

$$NUM_{TP,BD,GCC} = GCC_{BD} * tp_{r,bd} \qquad (2)$$

If the total rate of transportation for a building tpr_{bd} [1/m³] is based on the building shell, finishing and technical installation (gross cubic content), the total value resulting from eq. 3.

$$tpr_{bd} = tpr_{bd,cs} + tpr_{bd,fi} + tpr_{bd,ti} \qquad (3)$$

The rate of transportation may be based on individual trades, or it refers to a rate of transportation for the entire building. For example, the rate of transportation for the construction shell $tpr_{bd,cs}$ [1/m³], is calculated according to eq. 4.:

$$tpr_{bd,cs} = \sum_{i}^{n} tpr_{bd,trd,i} \qquad (4)$$

Roughly, the rate of transportation for concrete works based on the gross cubic content between 0.020 and 0.025 [1 / m³] can be assumed.

If Only the concrete works are considered, the rate of transportation for the reinforced concrete works $tpr_{cs,rcw}$ [1/m³] will be calculated from eq. 5 (whereupon here for the rough planning, three trades have been outlined):

$$tpr_{bd,rcw} = tpr_{fw} * fr_{bd} + tpr_{rw} * rr_{bd} + tpr_{cw} \qquad (5)$$

The proportional factors of the rates of transportation (based on the amount of concrete) for the formwork-, reinforcement- and concrete transports are added together. In the first term the

rate of transportation for the formwork is multiplied by the rate of formwork fr_{bd} [m²/m³]. By multiplying the rate of transportation for the reinforcement with the reinforcement ratio rr_{bd} [kg/m³], it results the second term [3].
Roughly, the rate of transportation for reinforced concrete works based on the quantity of the concrete of the building can be assumed between 0.15 and 0.20 [1/m³].
With eq. 6, the number of transportation based on the amount of reinforced concrete $NUM_{TP,BD,RCW}$ [-] can be calculated. By multiplying the rate of transportation $tr_{cs,rcw}$ [1/m³] with the total concrete volume $C_{V,BD}$ [m³] results the value for the total number of transports.

$$NUM_{\mathrm{TP,\,BD,\,RCW}} = \mathrm{C}_{\mathrm{V,\,BD}} * \mathrm{tpr}_{\mathrm{bd,\,rcw}} \qquad (6)$$

Additionally, an mark-up $MU_{TP,RCW}$ [%] can be considered and by inserting the percentage in eq. 7, get the total number of transports $NUM_{TP,BD,RCW,MU}$ [-].

$$\mathrm{N}UM_{\mathrm{TP,BD,RCW,MU}} = \mathrm{N}UM_{\mathrm{TP,BD,RCW}} * \left(1 + \frac{MU_{\mathrm{TP,RCW}}}{100}\right) \qquad (7)$$

If the gross cubic content is known, the amount of a reinforced concrete structure C_V [m³] can be calculated approximately by means of the eq. 8. In the numerator the gross cubic content GCC_{BD} [m³] and in the denominator of the rate of the cast-in-place concrete $cpcr_{bd}$ [m³ GCC/m³ concrete] are used.

$$C_{\mathrm{V,BD}} = \frac{\mathrm{GCC}_{\mathrm{BD}}}{cpcr_{\mathrm{bd}}} \qquad (8)$$

For structures in high rise buildings with walls and slabs made of cast in place concrete is the rate of cast in place concrete from 4 up to 7 (the rate of cast in place concrete = 7 e.g. for high-rise buildings with the rate of form work of about 4 m²/m³). Bearing walls are partially made of e.g. masonry; a lower rate of cast in place concrete is to use [3].

3.2 DETAILED PLANNING

Subsequently, the rate of transportion is determined separately for formwork, reinforcement and concrete work.
For the formwork results the rate of transportation tpr_{fw} [1/m²] based on the area of the formwork (one way) from eq. 9:

$$\mathrm{tpr}_{\mathrm{fw}} = \frac{\mathrm{MT}_{\mathrm{RQ}}}{FWA_{BD} * \mathrm{F}WA_{TP}} \qquad (9)$$

In the numerator is to use the total material requirements MT_{RQ} [m²] in formwork. Values for the total area of the formwork of the building FWA_{BD} [m²] and the average area of formwork FWA_{TP} [m²], which is delivered by each transport, are to put in the denominator. For rough consideration, the rate of transportation for the formwork based on the total area of the formwork from 0.00083 to 0.00125 [1 / m²] can be assumed [3].
For a further detailing of the detailed planning of procurement logistics various structural components are to be considered separately. Furthermore, it can be differentiated in the construction phases or production stages. In addition the specific values for material requirements $MT_{RQ,i}$ [m²], area of formwork FWA_{BD} [m²] and formwork quantity per transport FWA_{TP} [m²] is to put in eq. 10.

$$\mathrm{tpr}_{\mathrm{fw,i}} = \frac{\mathrm{MT}_{\mathrm{RQ,FW,i}}}{FWA_{BD,i} * \mathrm{F}WA_{TP,i}} \qquad (10)$$

From the specific rates of transportation $tpr_{fw,i}$ [1/m²], an average of the rate of transportation of the entire building tpr_{fw} [1/m²] can be subsequently calculated according to eq. 11.

$$\mathrm{tpr}_{\mathrm{fw}} = \frac{\sum_{\mathrm{i}}^{\mathrm{n}} \frac{\mathrm{MT}_{\mathrm{RQ,FW,i}}}{\mathrm{F}WA_{\mathrm{TP,i}}}}{FMA_{\mathrm{BD}}} \qquad (11)$$

For the reinforcement works, the rate of transportation tpr_{rw} [1/t] based on the reinforcement quantity results from eq. 12:

$$tpr_{rw} = \frac{1}{RW_{Q,TP}} \qquad (12)$$

In the denominator, the average amount of reinforcement $RW_{Q,TP}$ [t] is used which is delivered by each transport. For roughly calculation, the values from 0.05 to 0.1 can be assumed. With an average of 20 t per transport is to put 0.05 and 0.10 for 10 t. The amount of the value depends mainly on the specific site boundary conditions (e.g. nature of the access roads, weight limitations).

For the concrete works result the rate of transport tpr_{cw} [1/m³] based on the amount of concrete $C_{Q,TP}$ [m³], which in average delivered by each transport from eq. 13:

$$tpr_{cw} = \frac{1}{C_{Q,TP}} \qquad (13)$$

The denominator is the average amount of concrete (constant concrete amount), which delivered by each transport. For a rough calculation, the values from 0.07 to 0.15 can be assumed. For example, for an average of 10 m³ per transport the value of 0.1 can be assumed for the rate of transportation. The amount of the value depends mainly on the specific construction boundary conditions (e.g. quality of access roads or weight limitations which have an impact on the size of the vehicles) and on the construction period.

4.DETERMINISTIC AND SIMPLIFIED STOCHASTIC CALCULATION OF THE NUMBER OF TRANSPORTS

As input values for subsequent calculations, values can be used, for example from past projects, from literature or personal experiences. It is in all cases to ensure that the values are adapted to the construction site-, building-, management- and construction method conditions.

4.1.CALCULATION MODE 1 - DETERMINISTIC APPROACH

According to a calculation mode 1, it is for each calculation in each case, a value for the number of transports is determined. The parameters can be selected so that it is determined an upper and lower limit for the required magnitude.

For the probability of occurrence of the calculated values with this method, no declaration can be made.

4.2.CALCULATION MODE 2 - SIMPLIFIED STOCHASTIC APPROACH

For the input values in the calculation algorithm, three values are applied, namely a minimum value, an expected value and a maximum value. These values are multiplied by the respective, subjectively defined probability of occurrence. By adding the three products we get the most subjective probable value. This calculation has been in [5] discussed in more details.

With this method no declaration can be made about the probability of occurrence of the calculated values. Expectation values can have more weight, as well as minimum and maximum systematically are taken into account.

4.3.CALCULATION MODE 3 - USING MONTE CARLO SIMULATION

For the stochastic calculation method, individual selected parameter subjects to a distribution function are recorded (flow chart see Figure 1). The values for the range and the expected value will be determined taking into consideration the project specific boundary conditions.

By including of probability considerations in the calculations a significant improvement in the results is possible. Due to the ranges and distribution functions, it is represented according to the selected number of iterations for the desired values distributions of the probability. With the Monte Carlo method it is possible for the number of transports for the reinforced concrete works to calculate the distribution of probability. In an arbitrary number of iterations generates a software program (in this case, @ RISK) for the input values random numbers that occur in each case with the predefined distribution functions, and combines them according to a calculation provision (the calculation equations of the deterministic method). Input parameters are: ranges, expectation values and distribution functions.

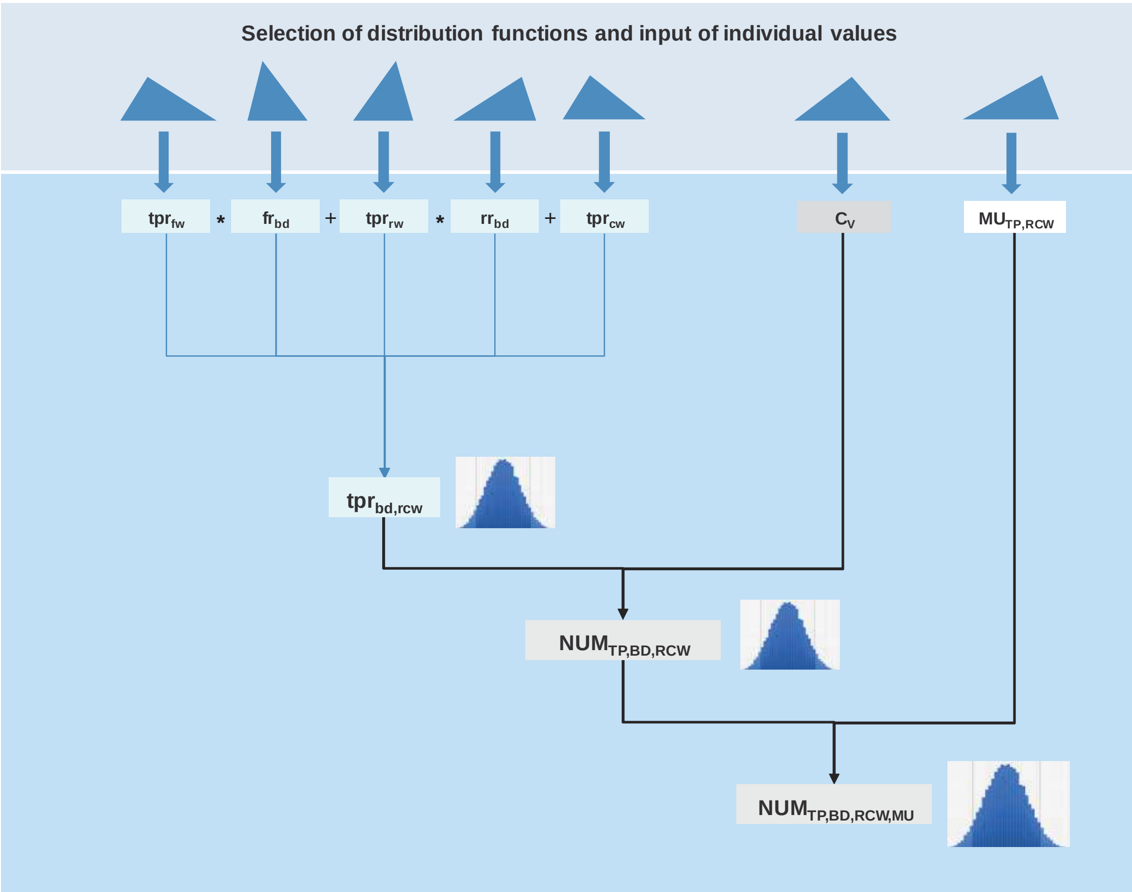

Fig . 1. Calculation Mode 3 – number of transports: Flow chart (following [4])

Raaber in [6] leads to distribution functions, so that for studies in construction in those cases where limitations are clearly to find as good as ever, are to bring triangular, parabolic or rarely rectangular distributions.

5.APPLICATION OF CALCULATION METHODS

In the paper, the application of the Monte Carlo simulation is presented on the basis of a high rise building project. The application of calculation methods 1 and 2 was discussed in [5] for the same project.

5.1.HIGH-RISE BUILDING PROJECT - ESSENTIAL INFORMATION

In Figure 3 the plan of the standard floor is given. The building has two basements, a ground floor, 10 standard floors and an attic floor (see Figure 3). The max. building area in the basement is approximately 3,025 m². The two basement floors, the ground floor, the standard floors and the attic floor usually have four different floor plans. Individual structural elements are on multiple floors are almost identical.

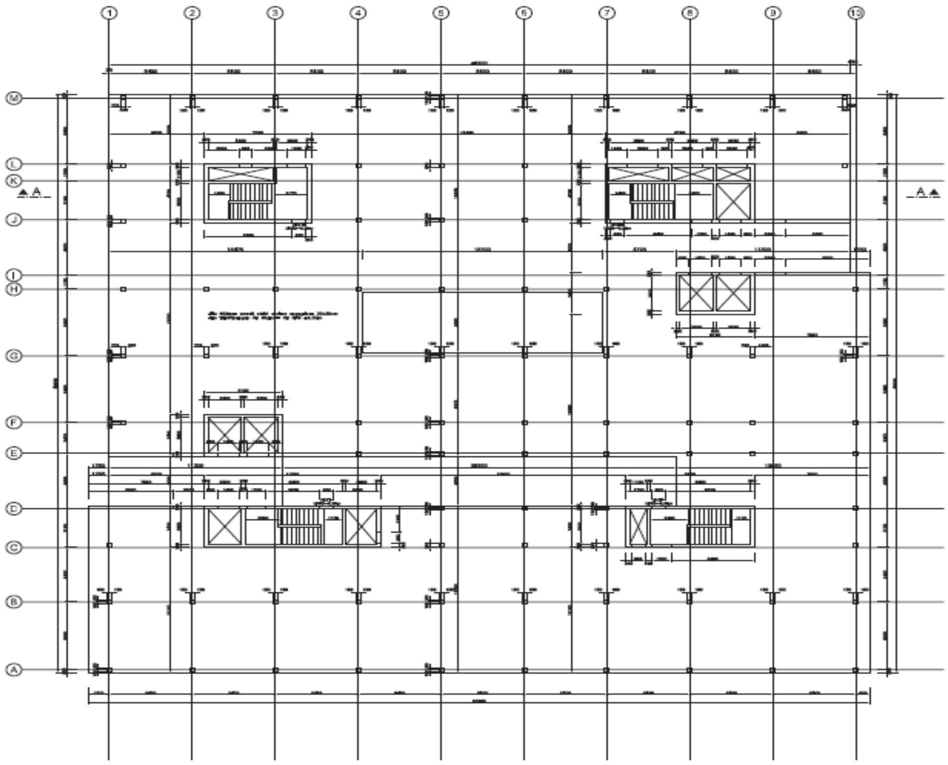

Fig. 2. Floor plan – standard floor (Doka [1])

The high rise building comprises 14 floors (including attic floor) and the dimension of the standard floor is usually about 50 m * 47 m.

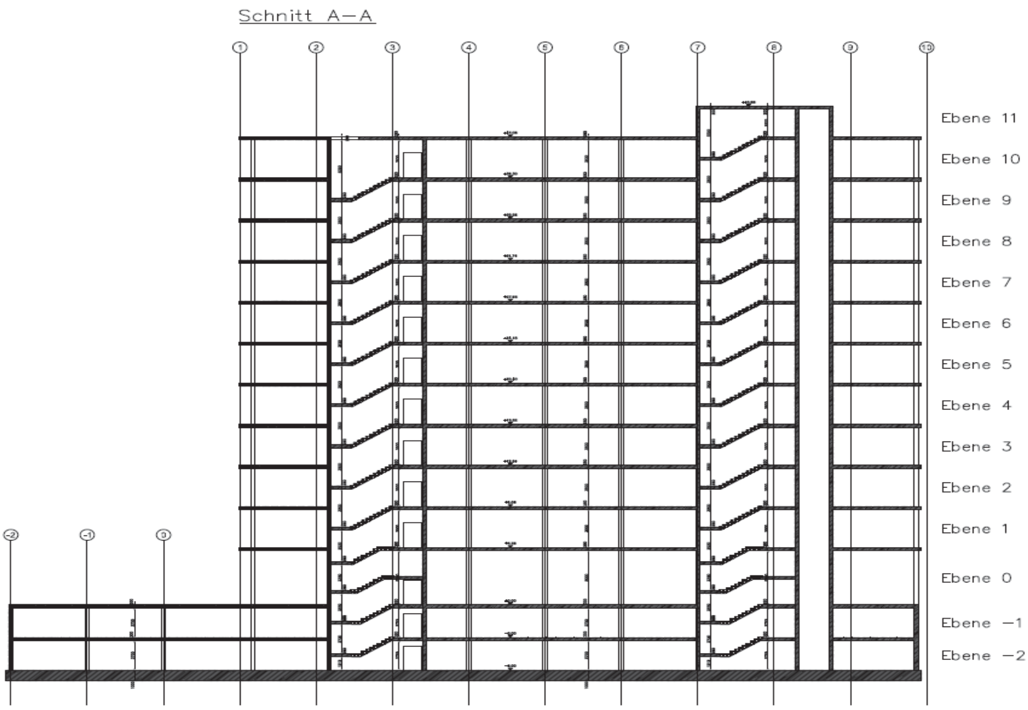

Fig. 4. Section (Doka [1])

Data for the quantities of formwork, reinforcement and concrete are given in Table 1. The quantities result from the calculation of quantities of the available plans. With the area of formwork of about 49,300 m² and the quantity of about 12,600 m³ of concrete, the rate of formwork results for the entire building with about 3.9 m²/m³. The ratio of reinforcement is calculated from the reinforcement- and concrete volume, with about 147 kg/m³.

Table 1: Quantities of formwork, reinforcement and concrete

Components	Formwork area		Reinforcement quantity		Concrete volume	
	[m²]	[%]	[t]	[%]	[m³]	[%]
1	2	3	4	5	6	7
Foundation plate	**225**	0,46	**431**	23,28	**3.080**	24,39
Walls	**5.553**	11,26	**103**	5,56	**739**	5,85
Columns	**3.598**	7,30	**89**	4,81	**270**	2,14
Shafts and cores	**15.554**	31,54	**266**	14,37	**1.902**	15,06
Slabs	**24.386**	49,45	**962**	51,97	**6.638**	52,56
Amount:	**49.316**	**100**	**1.851**	**100**	**12.629**	**100**

5.2.SOLUTION - CALCULATION MODE 3: MONTE-CARLO SIMULATION

To calculate the rate of transportation for the Monte Carlo simulation, the values are used from Table 2. A total of 50,000 iterations of a calculation with the program @ RISK are carried out. By this number of iterations, there are not significant changes in the quantiles (X_5 und X_{95}).

Table 2: Input values to calculate the number of transports

	MIN	EXP	MAX
Rate of transportation - formwork	0.0110 1/m²	0.0120 1/m²	0.0150 1/m²
Formwork ratio	3.60 m²/m³	3.90 m²/m³	4.00 m²/m³
Rate of transportation - reinforcement	0.0750 1/t	0.0850 Std/t	0.0950 1/t
Reinforcement ratio	140.00 kg/m³	150.00 kg/m³	160.00 kg/m³
Rate of transportation - concrete	0.10 1/m³	0.12 1/m³	0.14 1/m³
Rate of transportation - mark-up	5.00 %	6.00 %	8.00 %
Concrete volume	11,700.00 m³	12,629.00 m³	13,200.00 m³

As distribution functions weighted triangles are used. The result of the calculation is shown for the number of transports including an additional value as a probability distribution in Figure 5.

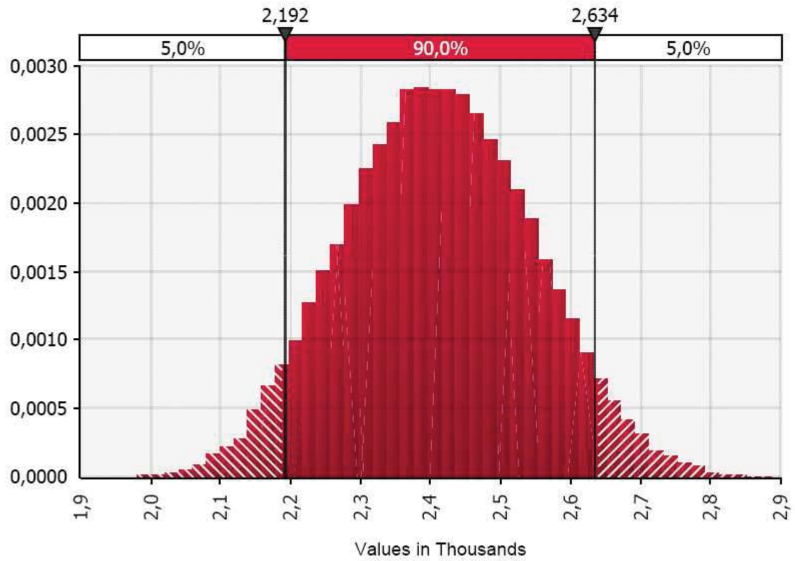

Fig. 5. Probability distribution for number of transports, including mark-up (@RISK [7])

The number of transports for the reinforced concrete works is with a probability of 90% between 2,192 [-] and 2,634 [-], so that the range is 442 [-]. That the number of transports more than 2,634 [-], lies with a probability of 5% (X_{95}). With a probability of 5% the number is below 2,192 [-] (X_5). The expected value („Mean“) is about 2.412 [-]. The standard deviation is 134 [-].

6. SUMMARY

In the paper, main influences on the procurement of logistics were presented. For the rough planning of the procurement logistics for Shell Construction Phase were three options presented and one of them explained in detail in order to calculate the number of transports. To take into consideration the inaccuracy of the data from the building, construction site conditions, construction method conditions and the approaches for the rates of transportation it was described, how these uncertainties can be considered systematic, stochastic in the calculation. The probability distribution for the number of transports relating to the reinforced concrete works was calculated using the Monte-Carlo simulation with the program @ RISK.
With increasing of the detailing of the project, the inaccuracies and uncertainties are also decreasing. An absolute reduction in the inaccuracy is not possible. Also for detailed consideration of the logistics for individual trades, construction phases or structural elements, the shown procedure can be applied.
This method, for example in the comparison of the transport logistics between different construction methods can be applied (e.g. comparison between cast-in-place concrete construction and constructions with different concrete types).
By presenting the relationship between the number of transports and their probability of occurrence, the reliability of the decision can be further increased.
Further studies on the characteristic of distribution functions for rates of transportation and the parameters of the construction (such as ratio of formwork, ratio of reinforcement) will be carried out. The effects of correlations between the input variables are also checked for their relevance. Their results will be published.

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