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CALCULATION OF THE LABOR CONSUMPTION RATE FOR SHUTTERING WORKS WHILST CONSIDERING UNCERTAINTIES

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Calculating construction costs and times is one of the most important and demanding tasks in construction management and economics. To arrive at a realistic calculation base, valid data and information is constantly being sought for labor consumption rates, output rates, productivity, material consumption, volumes in stock, number of transport cycles, and cost and time parameters that must be estimated or calculated *ex ante*. Ultimately, final cost and time parameters must be determined on the basis of such considerations and calculations. Accurate figures must be stated or submitted at the end of any analysis. These depend on the complexity of the building and on the conditions prevailing at the actual work stages and rely on more or less uncertain input data. One possible solution to this issue is to consider ranges that can deliver final conclusions on determined values. To systematically consider ranges in input parameters, this paper concentrates on applying probabilistic calculation methods based on Monte Carlo simulations. Key outcomes of probabilistic calculations include histograms that are used to directly capture the chance/risk ratio relative to a specific (selected) parameter. This paper presents a practical example of calculating the labor consumption rate for shuttering works to highlight the significance of the chosen chance/risk ratio and to show how it can be integrated into the systematic decision-making process adopted by the parties involved in the project.

Keywords: Monte Carlo simulation, Distribution function, Productivity, Histogram.

1 INTRODUCTION

Efficient construction management relies on the commercially optimal combination of production factors. The labor consumption rate is used to describe the amount of labor required to achieve this combination. Productivity serves as a measure to capture the efficiency of production factor utilization. Output values determined in thorough studies are considered to be a fundamental prerequisite to arrive at time periods that are realistic from a construction management point of view.

The labor consumption rate is the single most important indicator for preparing forecasts in construction management and economics as well as assessing labor-intensive activities. This parameter is used to establish a direct relationship to the requirements that can be derived from the production system. Labor consumption rates are of high significance to bidders and contractors as well as property owners and clients when it comes to determining construction time and cost. Labor consumption rates, such as for shuttering works, are mainly influenced by the following factors:

- general site conditions and general operational conditions
- specific structural conditions
- influences arising from the construction method

On the basis of calculated total hours and specific production quantities required for a certain type of work, a plan/actual comparison or final costing exercise makes it possible to calculate the labor consumption rate of a given activity or process, or groups of processes, such as in relation to shuttering works (Hofstadler 2014).

Labor consumption rates CR [wh/QU] result from dividing the total of paid working hours WH by the production quantity QU and are calculated using Eq. (1).

$$CR = \frac{WH}{QU} \quad (1)$$

As part of the situational analysis conducted in the quotation phase, influences on labor consumption rates are analyzed in order to assess the complexity of works. Individual types of work must be clearly delineated from each other in terms of time and activity to arrive at sound labor consumption rate values, avoiding shifts to other works and duplicate data collection.

Sound information regarding structural, site and operational conditions is indispensable to capture data in a systematic manner. This additional information should improve the accuracy of determining (calculating) labor consumption rates on the basis of existing documentation of future projects. Options to determine the magnitude of labor consumption rates include:

- experience – estimates
- costing manuals
- calculations – nomograms
- reporting – final costing
- work studies – tabulated guide values
- manufacturers' specifications
- simulation of the work sequence

From a contractor's point of view, influences arising from the entire (internal and external) production system should always be considered when calculating labor consumption rates in the quotation phase. In the quotation process, the final value should always be established whilst assessing the chance/risk ratio. If an exceedingly low value is chosen, the potential chance of achieving or even underrunning this value at the subsequent execution stage is also very low.

To get a contract in the first place, bidders inevitably prepare a tight cost schedule and thus select labor consumption rates associated with low chance/risk ratios. During execution, such tightly calculated cost schedules require maximum efficiency when combining production factors. For the relevant costing parameters, it is essential to know the chance/risk ratio established by applying the selected methods, and to include this ratio in subsequent considerations.

3 DECISION MAKING IN THE PRESENCE OF UNCERTAINTY

Any decision will always be fraught with uncertainties, including decisions with respect to the magnitude of parameters used for calculations. The notions of "uncertainty" or "risk" are used in many areas and intermingled in some cases. Basically, however, two concepts should be distinguished when referring to the notion of "risk" (see Figure 1). Reference is always made to positive or negative variances of a planned target from an identified actual value. On the one hand, "risk" merely refers to negative variances, whereas potential positive variances are called "chances". On the other hand, the concept of "risk" includes the possibility of both a positive ("chance") and a negative variance ("hazard"). In the latter case, "risk" implies both the hazard and the chance.

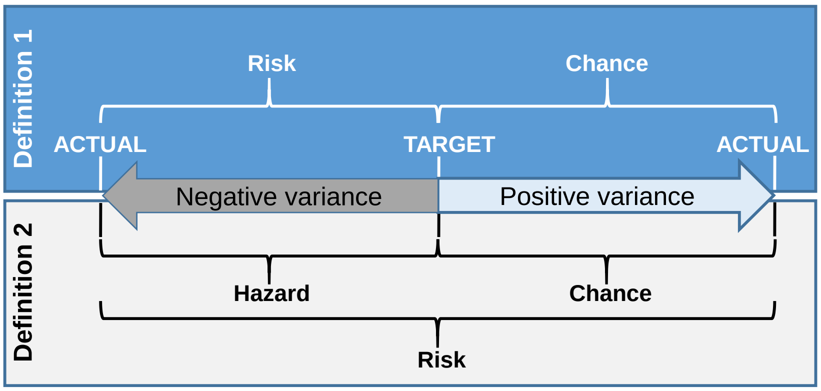

Figure 1. Concept of chance and risk (Kummer 2015).

Many definitions in the literature show that the concepts of chance and risk are by no means used in a consistent manner (e.g. Jonen 2007, Wiggert 2009, Kummer 2015). This is why the following sections include clear definitions of terms and explain their significance for being used in this paper.

If negative variances from the target are expected (i.e., damage or loss), the term "risk" is subsequently used if both the consequences and the probability of occurrence are objectively known (on the basis of a sufficiently large database) or can be estimated subjectively on the basis of past experience. Conversely, the notion of chances is used if positive variances are expected and if their consequences and probabilities of occurrence are also known (objectively or subjectively). Risk and chance are thus horizontally equivalent concepts (Kummer 2015).

4 CALCULATION OF LABOR CONSUMPTION RATES FOR SHUTTERING WORKS WHILST CONSIDERING UNCERTAINTIES

Relevant influences on the production system must be correctly captured and assessed to be able to select realistic labor consumption rates. Any such assessment must give rise to the calculation or selection of a number to represent the labor consumption rate of a specific output. Uncertainties that input parameters are associated with result from both quantities and labor consumption rates as such. In terms of quantities, the question arises how specified quantities will change at the detailed design and execution stages. Furthermore, it is crucial to come up with a realistic estimate of the ratios of standard and infill areas. Figure 2 shows the calculation sequence for determining the labor consumption rate of shuttering works for a complete building (Opera House project in Linz, Austria). In this example, triangular distributions are applied to the following input parameters: quantities, labor consumption rate (CR) for standard areas, share of standard areas in quantities, and CR for infill areas. These are then defined by the following three values: minimum value, expected value (as the mode of distribution) and maximum value.

Experts are able to vary the distances of the values to each other, the resulting shapes of the triangles, and thus their influence on the calculation process. In principle, symmetrical or asymmetrical triangles are possible.

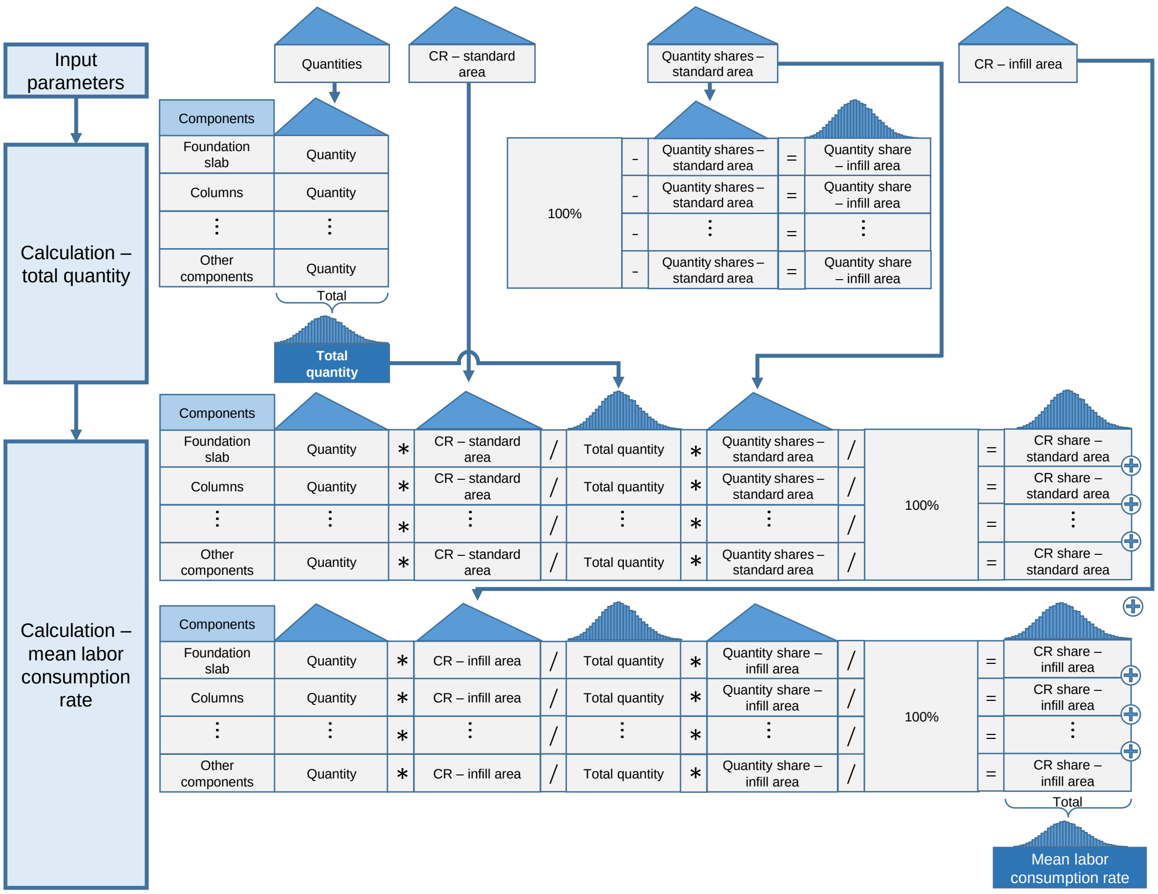

Figure 2. Calculation sequence to systematically account for uncertainties when determining labor consumption rates – application to shuttering works for a complete building (Hofstadler 2016).

When calculating formwork areas, there is the option of standardizing the total quantity to the specified value or to let it vary within a certain range. In the case at hand, for example, the total quantity moves within the range resulting from adding up the uncertain individual quantities for groups of structural components.

In addition, the percentage shares of standard areas are indicated as triangular distributions (broken down to groups of components); these can then be used to determine the individual infill area ratios adding up to 100% in each case.

In the block referred to as "Calculation – mean labor consumption rate" (see Figure 2), consumption rates (of standard and infill areas) are stated as triangular distributions for each group of components. Labor consumption rates of shuttering works are represented by histograms for the individual component groups (not shown in this paper). Thereafter, labor consumption rates are calculated for the individual quantity percentages, and added up. The total of the individual labor consumption rates calculated for each percentage ultimately results in the distribution of the total labor consumption rate of shuttering works for the entire building.

Probabilistic calculations are carried out numerically using Monte Carlo simulations (Latin Hypercube sampling with 50,000 iterative steps in each case), assuming uncorrelated input parameters in the example discussed in this paper. Theoretical characteristics, empirical data collection and expert surveys (and their combinations) can generally be used to select distribution functions. (Hofstadler and Kummer 2017)

5 INTERPRETATION OF RESULTS

Figure 3 shows the histogram for the mean total labor consumption rate of shuttering works for a building construction project. The mean shown in the histogram amounts to approximately 1.34 wh/m² whereas the standard deviation is roughly at 0.04 wh/m². The minimum mean labor consumption rate derived from 50,000 iterations equals about 1.21 wh/m² whereas the maximum is approximately 1.47 wh/m².

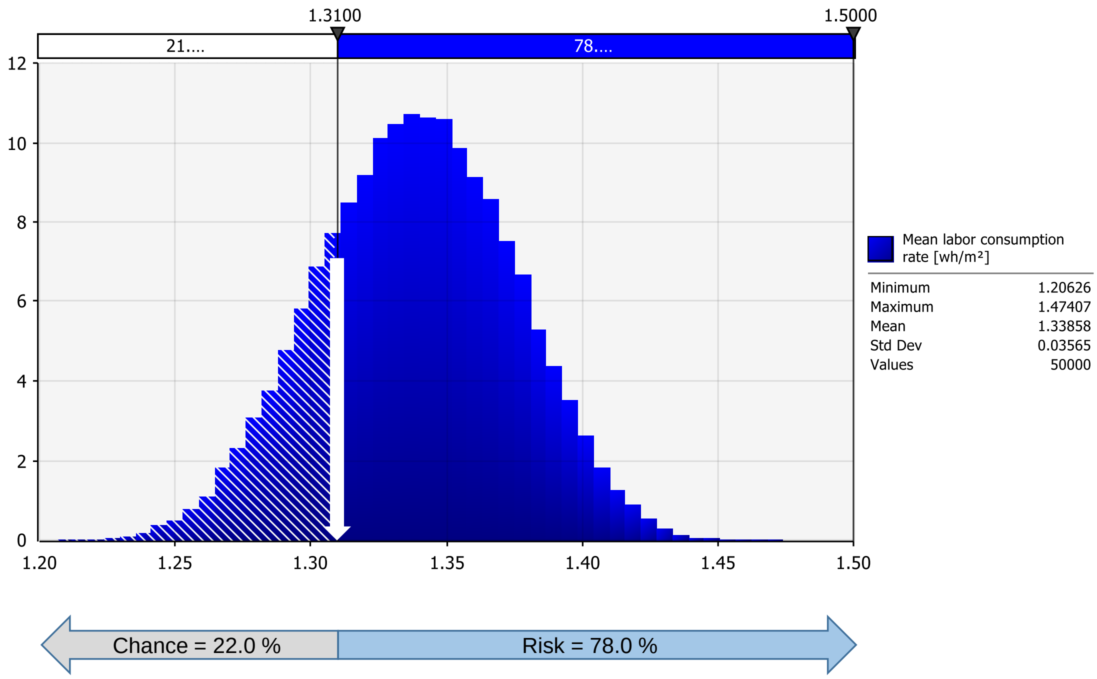

Figure 3. Histogram of the mean total labor consumption rate of shuttering works – chance/risk ratio relative to a deterministic value.

If the bidder quotes a specific (low) price for shuttering works to retain even a slight chance to be awarded the contract amid a fierce competitive environment, a retrospective calculation approach can be applied to determine the mean labor consumption rate of shuttering works that would have to be reached to be able to bid at the intended price. This labor consumption rate derived from the bid price by retrospective calculation can then be entered into the histogram shown in Figure 3. The slide controls included in the diagram make it possible to directly determine the corresponding chance/risk ratio associated with the deterministic labor consumption rate value.

If, for example, the retroactively calculated consumption rate amounts to 1.31 wh/m² (see Figure 3), there is a chance of only approximately 22% for the contractor to reach or underrun this value during the execution phase. In about 78% of cases, the applied assumptions result in a higher mean labor consumption rate of shuttering works. The bidder (or subsequent contractor) would thus run an increased risk if they applied this approach, but would still be able to prove the plausibility of the bid from a construction management point of view.

6 SUMMARY

The probabilistic calculation of labor consumption rates is associated with the advantage that "true" labor consumption rate values are shown, i.e., excluding speculative elements whilst considering inevitable uncertainties. Cost surveyors need not select a value within a given range for each of the input parameters. Instead, they can directly and systematically apply their experience and findings derived from the bid documents by defining ranges (minimum and maximum values) and, for example, by stating an expert (i.e., expected) value. Calculation results are visualized in histograms. Depending on their structure, these results can refer to the entire building, individual structural components, or specific work categories or items. Histograms deliver transparent information about the ranges to be anticipated and probabilities for specific deterministic values. The selected baseline has a major influence on whether to expect a positive or negative variance from the target. Depending on whether this baseline is selected to be higher or lower for a given labor consumption rate CR [wh/QU], the resulting probability of the actual labor consumption rate being below the selected baseline will be equally higher or lower. The proposed method makes it possible to develop corresponding computation models e.g. for concrete placement or reinforcement works.

The chance/risk ratio depends on the risk attitude of the company as well as on strategic considerations. In practice, bidders or contractors are usually closer to the risks rather than the chances because they need to apply a relatively low baseline due to their competitive environment. However, considering existing uncertainties in the calculation process enables the parties involved in the project to use the chance/risk ratio to reflect upon their decisions and to relate them to the market situation or to the order book and economic situation of the business.

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