MULTIFACTOR MODELLING IN CONSTRUCTION MANAGEMENT

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ABSTRACT : The paper presents a multifactor modelling of construction processes. There are three phases of the proposed extended procedure. Tools for these phases from chronometric test to verifying of the assumed model are indicated. Apart from the classic verification activities the method of artificial neural networks has been successfully applied. The paper presents the usage of these tools to model the process of assembly of structural corrugated steel plate structures.

Key words: Construction Management, Multifactor Modelling, Labor Consumption, Assembly of CSPS

1. INTRODUCTION

Construction processes are dependant upon many factors. In order to follow the basic engineering activity as modeling is one should incorporate influence of those factors on model result. Only then we may consider a model to be appropriate. However a complexity of factors can sometime create a substantial difficulty in expressing them within a model. A demand for compromise between accuracy of a model and its applicability is of paramount importance (c.f. [1]). As construction business is very much based on empirical approach thus any new model that is created should be well supported by reliable data. An ideal situation occurs when prior to construction of a model one can obtain data through extensive research addressing important features of modelled construction process. Assembly process of corrugated steel plate structures (CSPS) is influenced by many factors thus can be described as multi-factor process. There are different models for estimation of labor consumption and costs of assembly are used throughout the world today. A comparison of results of labor consumption predictions with use of those models has been recently performed in Poland [2]. This comparison showed that those models can be described as "closed" as they will not simulate sensitivity of results based on change of specific group of factors. During 1996 to 2002 field chronometric study covering 162 various cases of installation of flexible structures has been conducted by Janusz [2]. This extensive research have been carried our mainly in Poland and referred mostly to 148 CSPS with corrugation of 150*50 mm. Results from this research were compared with predictions obtained from identified 13 methods for estimation of labor consumption from four continents (Europe, North America, Australia, Africa). It showed substantial differences in output (labor consumption). It led to conclusion that there's a need to develop a new model for labor consumption predictions. Complete considerations of the new model and description of assembly process have been presented in [2]. This paper briefly described the protocol of creating a multi-factor model called LITCAC (**L**abor consumption, **T**ime and **C**ost of **A**ssembly of flexible **C**ulverts) including application of regression models, sensitivity analysis, artificial neural networks (ANN), ([3] and [4]), others. Practical application of the model with combination of multiple-criteria decision making support software called TOPSIS [5], show is usefulness for optimal decision making.

2. GENERAL PROCEDURE OF MULTIFACTOR MODELLING

In the case of a number of different factors (mentioned in Section 1) influencing the process of designing and implementing a project, what is necessary is multifactor modelling assistance of the process. Multifactor modelling is part of mathematical statistics, and is primarily based on multidimensional analysis of regression and on multiple and partial correlation

A correctly implemented procedure of such a modelling, which takes into consideration additional elements (methods) may bring interesting results. There are three phases of the proposed extended procedure. **The first phase** involves the following: chronometric tests, application of induction and isomorphism methods, testing statistical hypotheses, identification of groups of factors, for example, primary and secondary. **The second phase** consists of finding relationships between factors using the above mentioned regression and correlation, then a model of the tested process is built, and the degree of influence of changeability of factors on primary parameters, such as labor consumption, efficiency, or costs is identified. Therefore, we propose to introduce the so called sensitivity analysis. **The third phase** consists of verifying the

correctness of operation of the assumed mathematical model. Apart from the classic verification activities, such as checking, comparing errors, comparing the values of determination factors, the method of artificial neural networks has been successfully applied.
The use of these phases are described in next three Sections.

3. BASIC INFORMATION ABOUT PERFORMED RESEARCH

The research time framework spans 1996 to 2002. The investigated jobsites were mainly in Poland but some data origin from Sweden, Ukraine and Czech Republic. The research (test) set consisted of randomly chosen installation cases satisfying statistical rules of representation for general population. Used research method was chrono-metric measurement of duration of identified assembly processes, i.e. collection of time spent on separate processes during assembly performed on job site. It was conducted under all weather conditions that occur in Central Europe. The extracted test set analyzed during development of the modelling procedure consisted of 148 cases of assembled CSPS with various shapes (5), geometry and weight. All structures that were considered during the modeling protocol had a corrugation 150 mm*50 mm. The test set is considered as statistically significant according to Gliwienko rule [6].

Major elements investigated during the research consisted of:

1. labor consumption of identified assembly processes, time of assembly
2. number of people in assembly crews,
3. tools and equipment used,
4. assembly techniques applied,
5. assembly conditions(level of difficulty, temperature, weather, other)
6. parameters and shapes of assembled CSPS,
7. experience of assembly crews,
8. other (destination of the structure-culvert, bridge, underpasss; information about location, supervision).

To support data acquisition process many photographs were taken during assembly process in various installations and two cases have been documented also through recording on video camera. The way of reasoning was based on induction method procedure, which means that general conclusions were drawn based on detailed analysis. This procedure is very well described in [1]. Results of research were recorded on assembly cards and grouped into an aggregated data spreadsheet. Based on statistical analysis of the results, a number of key process factors and values (e.g. average output in identified processes, change of efficiency due to mechanization, number of tools applied, etc.) were obtained. Those were used later on for construction of a new model. The test set, which was called "principal", was divided into sub-sets, with use of isomorphic rules [1]. It allows obtaining sets with elements of identical features related to dividing criterion (similarity of shapes, similarity of assembly techniques, etc.). Dividing of "principal" set resulted in creation of 18 various sets of homogeneous elements. This concept is a clue for multi-factor model. It creates an interface between particular factors influence on a specific case within an identified group of installation cases, and other groups of cases. This interface was possible only due to number of collected data through detailed research and application of isomorphic rule. A schematic presentation of the division is presented in [1] and [7].

4. PROCEDURE OF ANALYSIS OF THE RESEARCH DATA

In order to evaluate results of the research a comparison analysis with results obtained from identified 13 methods (models) was made. Labor consumption was compared. In order to obtain a common platform for comparison, the existing models used as an input data recorded during collection of information performed in the research. A graph showing a comparison of the results is presented in Figure 1.
Investigation of assembly process allowed describing the sub-processes that occur during installation in a symbolic way. Recognized sub-processes are called primary processes and consist of:

1. internal transport of plates on the job site,
2. mounting of plates to shape the steel barrel,
3. bolting the plates together by means of bolts,
4. torque the bolts to required torque moment.

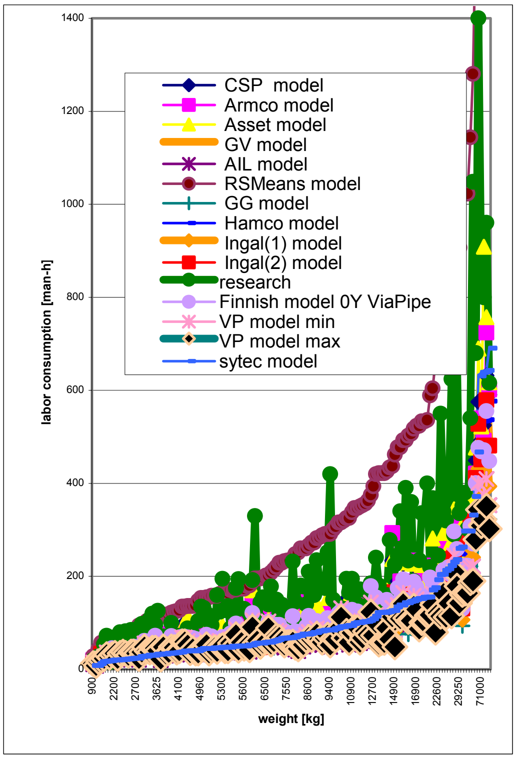

Figure 1. Comparison of results of labor consumption from existing methods and research

A division of factors affecting assembly has been proposed as follows:

1. group A: features of a structure: weight, number of plates, number of bolts, area of steel shell,
2. group B: assembly crew (number of workers, experience, motivation systems),
3. group C: used resources (electric wrenches, hand wrenches, cranes, scaffolds, etc.),
4. group D: assembly techniques (plate by plate, sub-assembly, full pre-assembly),
5. group E: external factors (weather, site conditions, other).

Factors included in groups B, C, D, E act on factors from group A, which results in assembled structure. Groups B, C, D contain factors can be changed by a contractor. Factors belonging to group A are fixed for specific case and factors belonging to group E are beyond the power of contractor; they are entirely independent and can't be controlled. Schematic presentation of action of factors is presented in Figure 2.

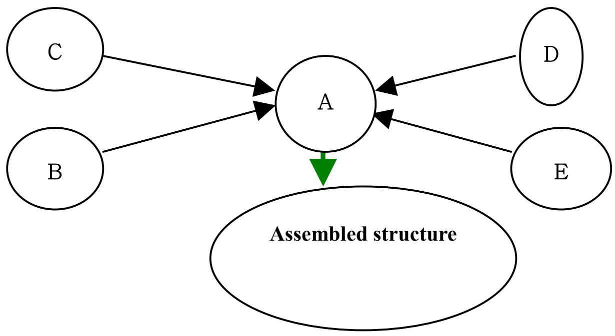

Figure 2. Schematic presentation of action of various groups of factors during assembly process

Based on statistical analysis efficiency factors for identified primary processes have been specified. The efficiency factors are additionally supplemented by indices, which represent an increase of outputs due to mechanization of works. An identical procedure has been performed for other sub-sets mentioned earlier. In order to evaluate interdependence of factors and sensitivity of results another analyses have been performed:

1. multi- and partial regression and correlation analysis
2. sensitivity analysis

Aggregated results of partial regression and correlation analysis for relation: labor consumption – weight of structure, for different shapes of structures, are presented in Figure 3. Based on multiple analyses of interdependence of labor and factors included in a group A, the weight of a structure was found most significant for dependence of labor consumption. A sensitivity analysis was performed in order to evaluate the sensitivity of results on change of various

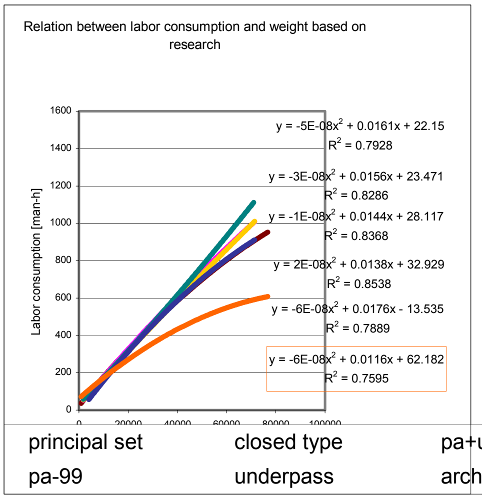

Figure 3. Aggregated regression models for dependence: labor consumption ─ weight

factors. The analysis was carried out for 7 different sets of factors with a help of software Statistica v.5. Results of one of them showing the sensitivity of labor consumption to change of use of mechanized wrenches (skr_zakr) and lifting equipment (sprzet) is presented in Figure 4. Conclusion from this analysis is that assembly process is sensitive to change of many factors and thus a model predicting the labor consumption must incorporate a mechanism taking this fact into account.

5. NEW MODEL AND ITS' VERIFICATION

Based on above presented considerations a new model (called LITCAC) for estimation of labor consumption has been proposed. This model is an "open" type model, which means that it allows change of many of input parameters and permits to observe the results of the change on labor consumption. Based on it one can estimate cost of assembly by introducing specific figures for cost items i.e. labor cost, cost of machinery, overall daily cost etc. As a subsection the model provides module for estimation of time of assembly counted in days (or shifts).

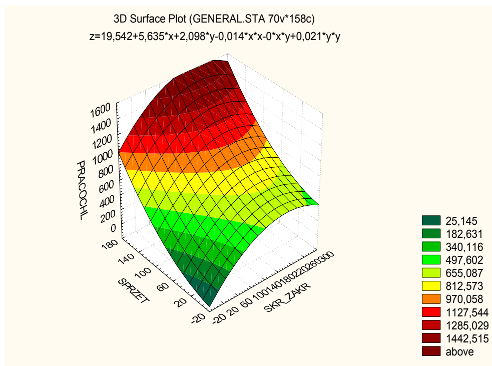

Figure 4. Sensitivity of labor consumption (Pracochl) to a change of use of lifting machines and mechanized wrenches

Mathematical notation of the model is expressed by four equations:

- Labor consumption of assembly,
- Time of assembly,
- Direct cost of assembly,
- Total cost of assembly including overheads and general construction daily costs.

These equations are quite extensive and contain different coefficients and corrective indices [2], [7].

Based on regression analysis the model provides user with information about confidentiality of prediction, i.e. gives estimated range of error and evaluates probability of estimation accuracy. Basically the level of accuracy ranks from: 0.79 to 0.96, depending on test sub-set. It describes the average probability of estimation accuracy. On top of that, for each estimate a range of error for resulted labor consumption is generated. This distinguishes LITCAC model from other existing models, which do not provide any information about confidence level of estimations. Verification of the model has been performed based on comparison with results of regression model and simplified model, which is related to hourly output, as well as to results of analysis with use of artificial neural networks (ANN) (based on BrainMaker Professional for Windows v.3). Additionally the model has been tested on separate cases of assembly that were not included in the test set. The verification of the model confirmed its' good applicability for predictions of labor consumption. Figure 5 presents comparison of average relative errors of estimation obtained from regression model, artificial neural networks and LITCAC. The artificial neural networks have had two layers with two input parameters (weight and number of bolts) and end results i.e. labor consumption.

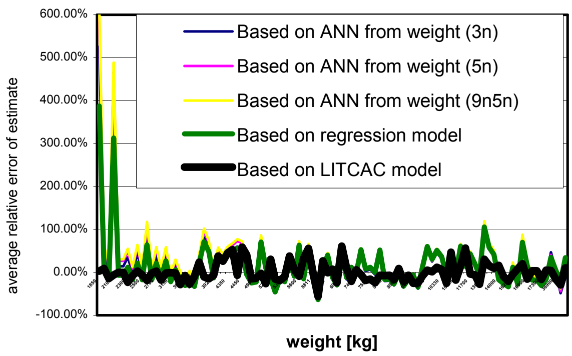

Figure 5. Comparison of average error of estimation of labor consumption obtained from regression model, artificial neural networks and LITCAC model for sub set "pa".

An average relative error for analyzed test sub-set ("pa") obtained from LITCAC model as well as its' dispersion was the lowest of compared models. The average relative error was calculated based on equation (1):

$$\varepsilon = (1/n)\sum_{i=1}^{n} ((P_{im}(x) - P_{ib}(x))/P_{im}(x), \quad (1)$$

where:

ε – an average relative error for applied model,

n – number of elements of investigated set,

$P_{im}(x)$ – labor consumption of assembly for specific structure based on applied model,

$P_{ib}(x)$ – labor consumption of assembly for specific structure based on research,

x – weight of a structure.

The average relative error of prediction (ε) for LITCAC model was ε = 0,44% with δ = 22,40% (standard deviation), whereas ANN resulted in ε =15,42% and δ = 71,57% and regression model resulted in ε =15,53% and δ = 58,49%. Comparison of results obtained with LITCAC model with research measurements and other methods are satisfying and profitable on the advantage of our model.

Figure 6 presents a simple graphical output from the LITCAC model (installation case with 5 workers equipped with different number of resources). One can notice change of results related to resources change.

This is end of the „pure" though extended multifactor modelling. But the proposed procedure and the use of the model can be considerably enriched through the addition of the module (of the model) of the optimization. Application of multi-criteria decision making methods MCDM (for example, TOPSIS, ELECTRE or ENTROPHY) together with LITCAC can yield an interesting effect in optimization of the process planning. Examples of that are presented in [7] and [8].

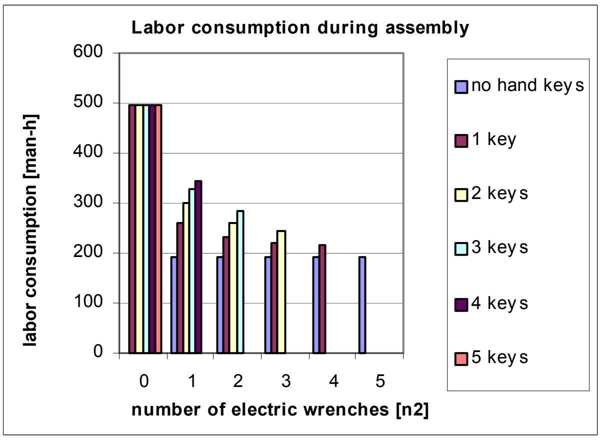

Figure 6. Result table obtained from LITCAC model

6. CONCLUSIONS

Presented procedure of multi-factor modelling in construction management shows importance of induction method in development of accurate model. Moreover this approach allows sound verification of model and helps users to understand the reasoning in detailed way. Presented model incorporates an interface between technology and economy, which is well present in reality. Utilizing results from LITCAC with use of MCDM models is very useful for optimization of assembly process. The new model is constructed in this way that it can be used worldwide after minor adjustments to specific markets.

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