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Original scientific paper

Thermal and Acoustic Insulating Gypsum Composite Material with Improved Water Resistance

Volodimir Kersh, Andriy Kolesnikov, Mikola Hlitsov, Sergii Gedulyan

Abstract: The article discusses methods for obtaining building heat and sound insulating composite material based on gypsum with high resistance to water. An additional characteristic is considered - the water resistance index, in which the role of material strength in the wet state is enhanced. The proposed characteristic is used to optimize the heat and sound insulating composition based on gypsum. The material contains matrix gypsum-cement-ash binder and a mixture of aggregates. The result of the planned experiment shows that the water resistance index more adequately reflects the strength of the composite in the wet state compared to the softening coefficient. An optimization of the complex properties of the composite is given in accordance with its intended purpose. As a result of the study, an optimal waterproof composition with improved thermal insulation and sound insulation characteristics was obtained.

Keywords: experimental statistical modeling; gypsum-containing composite; hierarchical optimization; softening coefficient; water resistance index

1 INTRODUCTION

One of the main tasks of modern building materials science is the development and implementation of materials characterized by improved operational, technological, and environmental qualities. Specific requirements, a high curing rate in particular, are imposed on materials for the manufacture of bases for self-leveling floors, as well as molding partitions [1, 2]. Gypsum and gypsum-containing composites are promising for improving thermal and acoustic comfort [3, 4]. In some cases, their use is limited to a significant decrease in strength when wetting products from those composites, especially with loose aggregates (for example, perlite, sawdust, etc.) [5], up to unprompted destruction in a water-saturated state.

The increase in water resistance of gypsum composites is carried out mainly in two directions:

1. Creating effective mixtures based on gypsum and cement with the mandatory addition of components with pozzolanic activity (ash and slag, tripoli, flask) [6, 7].
2. Internal and surface hydrophobization [8, 9].

The use of these techniques simultaneously leads to a synergistic enhancement of the water resistance of materials based on gypsum.

It is possible to increase the heat and sound insulation characteristics of the materials under consideration by adding to the mixture non-traditional aggregates with low density, low thermal conductivity and sound permeability – expanded polystyrene, cork crumb and granulated foam glass.

2 MATERIALS AND METHODS

Of the many multi-piece compositions that are applicable in considered areas, materials with an optimal set of performance properties are currently in demand, with the most significant performance properties being characterized by values close to optimal, and the rest – satisfying a set of regulatory requirements and restrictions [10]. For the intended use of the gypsum composite (base for floors), along with optimal thermal conductivity (minimum), sound permeability for airborne and impact noise (minimum), compressive strength (maximum), an important characteristic is water resistance (maximum). Presence of multi-criteria optimization problem for the composites along with restrictions that comply with the regulations standards is under consideration. Let us consider in more detail the characteristics of water resistance.

Water resistance of materials is usually estimated by a softening coefficient, equal to the ratio of compressive strengths in water-saturated and dry condition [6]: $K_s = R_w/R_{dry}$. The coefficient of softening of products from pure gypsum K_p = 0.3–0.5, which indicates its low water resistance.

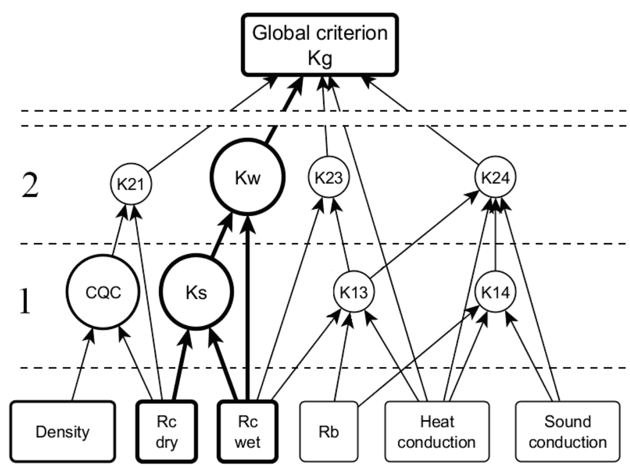

Figure 1 The hierarchical nature of the composite material's optimality criteria; K_s – softening coefficient, K_w – proposed water resistance index, *CQC* – coefficient of structural quality, R_c(dry) – compressive strength in the dry state, R_c(wet) – compressive strength in a water-saturated state

Along with the widespread softening coefficient, another characteristic seems to be useful - water resistance index K_w, coefficient in which the value of wet strength is "strengthened" as determining the possibility of using the material for wetting, $K_w = R_{wet}^2 / R_{dry}$ [11]. As will be shown later, K_w more accurately characterizes the water resistance of a material.

It is convenient to consider these characteristics of water resistance as certain particular combined criteria located on different tiers in a multi-criteria optimization scheme between individual performance characteristics and the hypothetical global *K*g criterion (Fig. 1).

Another example of partial criteria of an intermediate nature is the known coefficient of structural quality of a material [12] (*CQC*, Fig. 1), equal to the ratio of compressive strength of a composite to its density, $CQC = R_c / d$, which is useful for assessing the effectiveness of structural materials. This criterion, as a softening coefficient and water resistance index, is an element of a general hierarchical scheme for optimization of composites.

The features of water resistance characteristics are appeared during the optimization of a composite material based on a gypsum-cement-ash binder with the addition of heat and sound insulating aggregates (Tab. 1).

Table 1 The composition of the samples of the cement composition in the planned experiment

№	Coded values			
	Poly-styrene	Cork	Foam glass	Ash
1	0	1	0	1
2	0.5	0	0.5	1
3	0.33	0.33	0.33	−1
4	0	0	1	−1
5	0.5	0.5	0	1
6	0	0.5	0.5	−1
7	1	0	0	1
8	1	0	0	−1
9	0.33	0.33	0.33	1
10	0	1	0	−1
11	0.5	0	0.5	−1
12	0	0	1	1
13	0	0.5	0.5	1
14	0.5	0.5	0	−1

3 RESULTS AND DISCUSSION

The main operational characteristics of the samples are investigated, including compressive strength in dry R_{dry} (MPa) and water-saturated R_{wet} (MPa) condition. For a qualitative comparison of the water resistance characteristics of Ks and Kw, according to the degree of approximation R_{wet}, all values are normalized to unity by the formula $X_{norm} = (X - X_{min}) / (X_{max} - X_{min})$, where X − the initial property value for each sample, $X_{max(min)}$ − the maximum (minimum) value by sampling. The corresponding normalized values are shown in Fig. 2.

When comparing the normalized values of the characteristics of water resistance displayed in Fig. 2, it can be seen that for samples № 3, 8 and 14 (Fig. 2a) the softening coefficient K_s represents a clearly overestimated estimate of water resistance in terms of its main "target" parameter − R_{wet}. For sample № 12 (Fig. 2, b) K_s gives an underestimation of water resistance. The water resistance index K_w in all these cases reflects the water resistance more adequately.

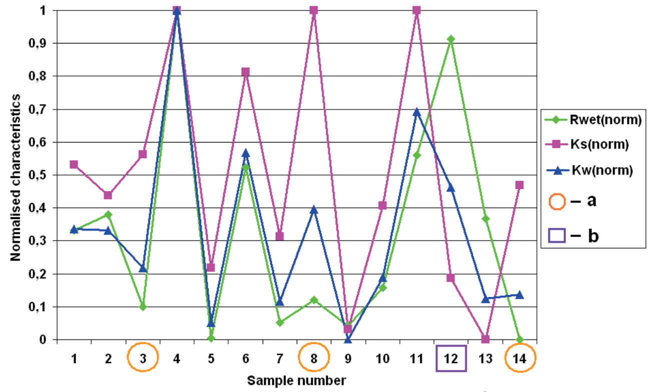

Figure 2 Normalized water resistance characteristics of the composite a − an overestimation of water resistance by K_s, b − is an underestimation of water resistance by K_s. Water resistance index K_w adequately assesses water resistance.

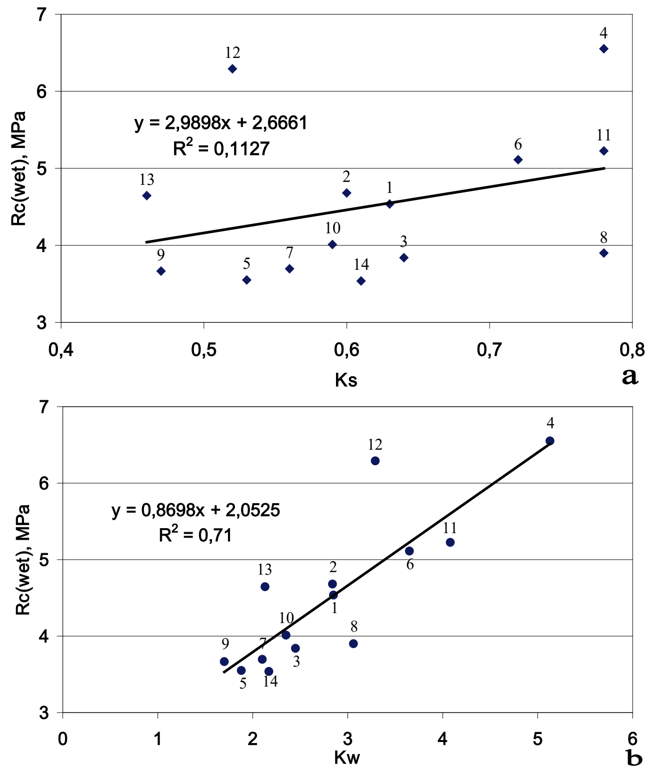

Figure 3 The nature of bond of strength in a water-saturated state of the softening coefficient K_s (a) and the water resistance index K_w (b)

The study of the statistical characteristics of the water resistance of 14 samples confirms this conclusion. The nature of bond of strength in a water-saturated state with a softening coefficient and water resistance index is shown in Fig. 3. No significant correlation of the softening coefficient K_s with the strength in the wet state R_{wet}, MPa is observed (Fig. 3a). At the same time, there is a clear correlation between the strength in a water-saturated state and the water resistance index, with the coefficient of determination R^2 =0.71 (Fig. 3b).

An additional advantage of the water resistance index in the task is its high discriminatory ability in a comparative analysis – it allows you to better distinguish the compositions by water resistance (Fig. 4).

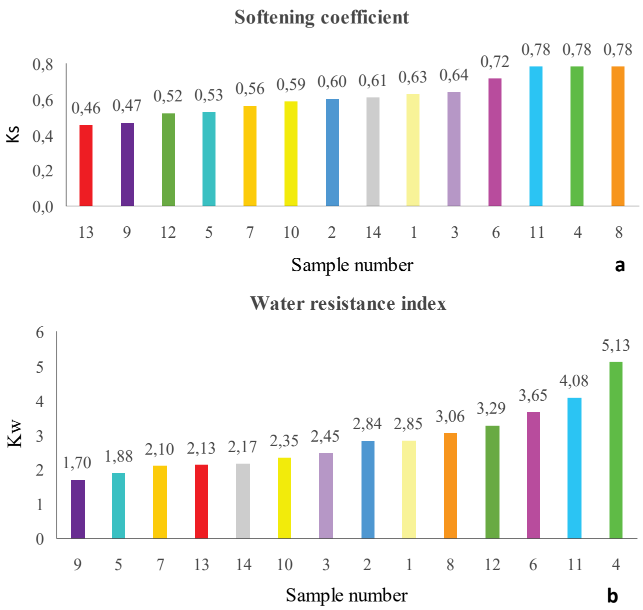

Figure 4 The softening coefficient K_s (a) and the water resistance index K_w (b) in a comparative analysis of multi-piece compositions.

Table 2 Experimental statistical models of water resistance

Softening coefficient K_s =		Water resistance index K_w =	
+0.6808∗Polystyrene		+2.5723∗Polystyrene	
+0.6119∗Cork		+2.6450∗Cork	
+0.6590∗Foam glass		+4.2009∗Foam glass	
−0.3593∗Polystyrene∗Cork		−3.0707∗Polystyrene∗Cork	
−0.0964∗Polystyrene∗Ash		−0.3885∗Polystyrene∗Ash	
−0.2443∗Cork∗Foam glass		−2.8576∗Cork∗Foam glass	
+0.0201∗Cork∗Ash		−0.9898∗Foam glass∗Ash	
−0.1189∗Foam glass∗Ash			
−0.2976∗Cork∗Foam glass∗Ash			
R-Squared	0.9656	R-Squared	0.9328
Adj R-Squared	0.9106	Adj R-Squared	0.8752
Pred R-Squared	0.6781	Pred R-Squared	0.7776
Adeq Precision	12.323	Adeq Precision	14.890

An analysis of the water resistance of a composite based on the softening coefficient (Fig. 4, a) equalizes by water resistance samples № 11, 4, 8 (K_s = 0.78). At the same time, the most significant performance characteristic related to water resistance – R_{wet} – is different for this samples: № 4 has R_{wet} = 6.6 MPa, № 8 has R_{wet} = 3.9 MPa, y № 11 R_{wet} =5.2 MPa. The softening coefficient K_s does not reflect this difference. At the same time, the water resistance index K_w more adequately reflects water resistance (Fig. 4, b).

We will conduct a comparative analysis of the effectiveness of using the water resistance index and the softening coefficient as responses in the planned experiment to optimize the composite. Experimental statistical models of these characteristics of resistance are shown in Tab. 2.

Graphic display of the resulted models is shown in Fig. 5 and 6. The softening coefficient (Fig. 5) takes the highest value with the minimum ash concentration (Ash = −1). In terms of the composition of the aggregate mixtures, the maximum K_s corresponds to a composite without cork components – the cork granules absorb water and swell, which contributes to the destruction of wet material. At the same time, the effect of polystyrene and foam glass, which do not absorb water, is almost the same – a line of compositions is observed with the same level of softening coefficient (K_s = 0.8).

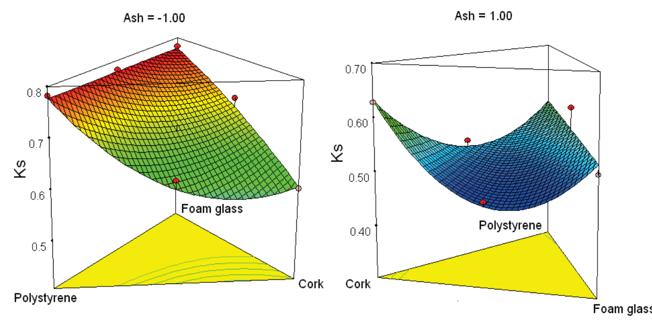

Figure 5 Display of experimental statistical models of the softening coefficient K_s

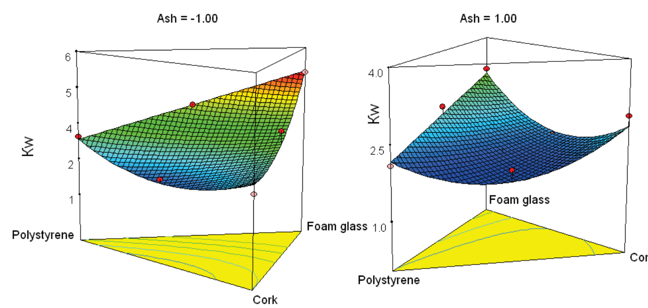

Figure 6 Display of experimental statistical models of water resistance index K_w

The highest value of the water resistance index (Fig. 6) is characteristic of the composition with the minimum ash content (Ash = −1) and the maximum foam glass content. A possible explanation for the positive effect of foam glass on the water resistance of the composite is the insularity of cells, as well as the increased strength of the adhesive contacts of the matrix material and foam glass. Cork filler reduces material strength under load due to swelling.

The peculiarity of the problem of optimization of water resistance of materials with the help of the proposed characteristic is the ability to maximize the water resistance index, while maintaining only the boundary requirements for the softening coefficient that are consistent with accepted standards. The considered characteristics together with other properties (heat engineering, acoustic, etc.) can be used in solving multi-criteria optimization problems.

With geometric optimization, areas corresponding to suitable compositions are distinguished on the factor plane. To implement this method, in accordance with the requirements for the materials of the type under consideration, the allowable limits for changes in performance properties are set (Tab. 3).

The diagram of geometric optimization, performed on the models of operational properties, is shown in Fig. 7. For the minimum ash content (Ash = −1), the range of permissible compositions is near the center of the triangle; all components of the aggregate mixture must be present. This can be interpreted as follows. Aggregates that are together in use in the composite, at their optimal proportions, mutually reinforce the positive properties of each other and partially neutralize the negative ones. At maximum ash concentrations (Ash = 1), no allowable areas are found.

Table 3 Allowable variation ranges for composite properties

Characteristics	Denotement	Units	Values
Density	d	kg/m^3	900-1100
Compressive strength	R_c	MPa	5-10
Flexural strength	R_b	MPa	0.5-1
Thermal conductivity	λ	W/(m·degree)	0,2-0,25
Sound permeability coefficient	Air noise	–	0.003-0.05
Impact noise (average amplitude)	Blow noise	мВ	700-1000
Softening coefficient	K_s	–	0.6-1
Water resistance index	K_w	MPa	3-5

Table 4 Optimization criteria and objectives

Criteria	Optimization objectives	Lower limit	Upper limit	Degree of importance
d	minimize	900	1100	2
R_c	maximize	5	12.1	4
R_b	in the range	0.5	1.06	-
λ	minimize	0.2	0.25	4
Air noise	minimize	0.025	0.05	3
Blow noise	minimize	700	1000	4
K_s	in the range	0.6	1	-
K_w	maximize	3	5	4
Desirability	maximize			

Another option is numerical optimization, in which the considered properties, which play the role of partial optimality criteria, are minimized to a single criterion, the "desirability function" [13-15] (Desirability). The objectives and optimization criteria, as well as the degree of importance of each of the exploited performance properties are shown in Tab. 4.

As a result of optimization, the most successful prescription solutions were selected (Tab. 5).

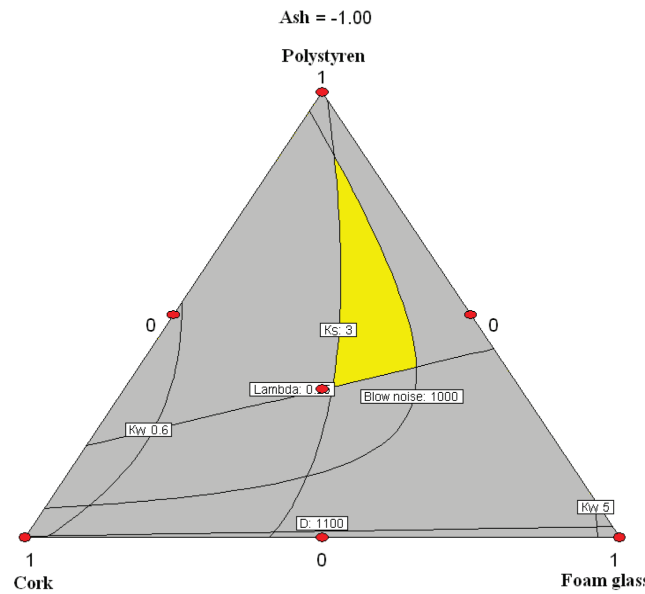

Figure 7 The range of allowable compositions of the studied composite

Table 5 Numerical optimization results

№	Polystyrene	Cork	Foam glass	Ash	d	R_c	R_b	Lambda	Air noise	Blow noise	K_s	K_w	Desirability
1	0.575	0.136	0.289	−1	1008	6.37	0.65	0.241	0.0335	972	0.73	3.21	0.19088
2	0.552	0.145	0.303	−1	1012	6.42	0.65	0.242	0.0335	971	0.72	3.22	0.19032
3	0.532	0.156	0.313	−1	1015	6.46	0.66	0.243	0.0336	969	0.72	3.22	0.18871
4	0.601	0.115	0.284	−1	1004	6.33	0.64	0.240	0.0334	981	0.73	3.25	0.18705
5	0.522	0.145	0.333	−1	1017	6.50	0.66	0.243	0.0336	977	0.73	3.29	0.18599

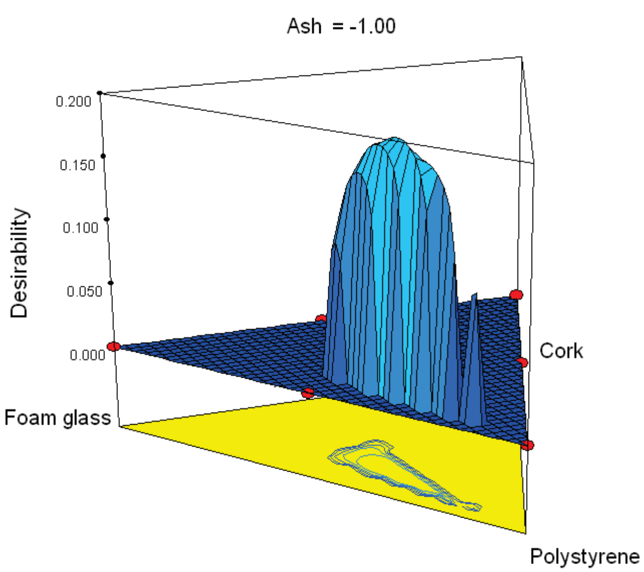

Figure 8 Shape of the function of the desirability of the studied composite

For the function of desirability, sharp maxima are observed in the region of permissible compositions, each of them corresponds to the optimal composition (Fig. 8). Small values of this function indicate the materiality of the restrictions and the multidirectionality of the requirements for the optimal composition.

As a result of optimization, a composition with improved characteristics was obtained in comparison with matrix material without aggregates: thermal conductivity is reduced by about 50%, sound insulation properties are improved by 35-50% for airborne noise and by 20-30% for impact noise. In this case, water resistance of the material is increased by 2 times (K_s = 0,73, K_w = 3,21). The resulting composition meets the intended purpose.

The proposed water resistance index K_w makes it possible to more objectively and accurately assess the degree of water resistance of materials, and to compare them with each other by this feature, since it:

1. Is statistically determined – higher values of wet strength usually correspond to a higher water resistance index,

which allows using it as an optimality criterion in materials science problems;
2. Has a clear physical meaning of given strength, $K_w = K_s \cdot R_{wet}$ (MPa);
3. Can be used as a particular or general optimality criterion for solving multi-criteria optimization problems for a complex of properties of composites.

4 CONCLUSIONS

1. A new water resistance characteristic of composite materials is being considered – the water resistance index, which has a number of advantages in comparison with the existing characteristics.
2. A hierarchical optimization scheme is proposed that combines the criteria for the quality of materials of varying complexity and generality, which allows purposefully forming a material with a set of specified characteristics.
3. The proposed approaches are applied to obtain the optimal formulation of the heat and sound insulating composite of high water resistance.

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Original scientific paper

Prediction of Effective Elasticity Coefficients of Composite Biofuel

Vasyl Klymenko*, Volodymyr Kravchenko, Vasyl Gutsul, Viktoriya Kravchenko, Viacheslav Bratishko

Abstract: It is suggested that fuel pellets made of composites based on solid plant waste should be considered as stochastic systems that are anisotropic in microvolumes but isotropic in the entire structure, i.e. quasi-isotropic in volume. Based on this hypothesis and the analysis of the known micromechanical models for forecasting physical and mechanical constants of composite materials, the expediency of using the Reuss-Voigt and Hashin-Strickman models to determine the effective elastic coefficients of composite biofuels is substantiated. The results of calculations made on these models for a number of two-component biofuel pellets are given. An experimental evaluation of effective Young's modulus and Poisson's ratio for two-component pellets with "straw + brown coal" composition was carried out. The obtained results of experimentally determined values of coefficients satisfactorily correspond to their calculated values: deviations are up to 26%. The Reuss-Voigt model was used in the calculations because the conditions required for the application of the Hashin-Strickman model are not met for composite pellets consisting of straw and brown coal. The results of the study will be useful in calculating or selecting press equipment for the production of quality fuel pellets from composites based on solid plant waste.

Keywords: biofuel; composite pellets; effective elastic constants; plant waste; Poisson's ratio; Young's modulus

1 INTRODUCTION

Plant agricultural waste, different types of wooden biomass and specially grown energy crops are significant biomass potential available for energy production [1].

To convert biomass into a form that is suitable for transportation and efficient energy use, a compaction process, known as pelletizing, is used.

The main advantages of using biofuel pellets are the following [1]:

- reduction of the harmful emissions into atmosphere: such fuel is CO_2-neutral, i.e. the amount of the carbon dioxide which emitted into the atmosphere during its combustion does not exceed the amount of emissions that would have been generated by natural decomposition of biomass;
- higher calorific value, which exceeding the value of bulk biomass and approaching the calorific value of coal;
- low cost compared to fossil fuel resources.

Improvement of the usage efficiency for different types of solid plant waste can be achieved through the production of pellets made from composite materials, including other carbon-containing materials (e.g. household waste polyethylene terephthalate (PET), local fuels) [1, 2].

Exploitation of these fuels in power plants should achieve a synergistic effect as a result of more efficient use of biomass resources and a partial reduction of the negative impact on the environment as a result of waste disposal.

In a process of designing of the technological equipment for the production of solid composite biofuel and its subsequent transportation and use, it is necessary to consider the physical and mechanical characteristics of biofuel made of composite materials, in particular the elasticity constants [1]. Since composite fuels can include different components in different proportions with different individual elastic constants, the question of determining their elastic constants as solids with corresponding new properties in relation to its individual components is important and relevant.

Analysis of recent research and the publications. The pellets quality and their production energy consumption depend on the design parameters of the press equipment, the pressure on the raw material, as well as its physical and mechanical characteristics [1, 3]. The required pressing pressure depends on both the technological and design characteristics of the press equipment and the elastic physical and mechanical properties of the raw material, namely the Young's modulus E and Poisson's ratio v [1, 3].

Values of elastic properties of such materials as coal, wood, polymers and others are widely presented in the literature [3-5]. As for the study's results to determine the elastic properties of solid plant wastes, such information is presented much narrower. Some data about the elastic coefficients of composites, including plant wastes, which are mainly construction materials and products made using wood chips, are given in [6]. Article [7] considered issues of analytical determination of elastic constants of composite materials of multilayer shells with reinforcing material on the basis of epoxy matrix EM-20, but the obtained results of research cannot be directly used to calculate the effective elasticity constants (EEC) of composite biofuel.

The aim of the paper is to substantiate the choice of methodology for predicting the EEC of composite biofuel based on plant wastes (Poisson's ratio and Young's modulus) and experimentally assess the possibility of its practical application.

The choice of structural model of composite biofuel. Composite materials (CM) or composites consist of two or more components: discrete elements, which are reinforcement or reinforcement components, and a matrix that binds them together. CM have specific characteristics that differ from the total properties of the elements that make them up [6-14].

By the type of reinforcing components, which include various fibers, powders, spheres, crystals and other particles of organic and inorganic materials, CM is distinguished [12]:

- multi-layered;
- fibrous, in which components of reinforcement are fibrous structures that can be oriented in different directions;

- filled with CM, in which the components of reinforcement are heterogeneous particles.

According to the nature of distribution of reinforcement components, CM can be divided into periodic systems, stochastic mixtures and structured compositions.

Depending on the geometry of the reinforcement components and their relative position, CM can be isotropic, whose characteristics are the same in all directions, and anisotropic, whose characteristics differ depending on the orientation. Quasi-isotropic ones include stochastically reinforced CM, whose reinforcing elements are short particles oriented randomly.

Composite fuel based on solid plant waste with an admixture of local fuels or household waste can be classified as stochastic systems whose components are chaotically distributed and do not form regular structures. At the same time, such a material is anisotropic in micro objects, but isotropic in the volume of the whole structure, that is, quasi-isotropic.

In composite biofuel (CMB) based on plant waste in the form of pellets or briquettes, the structure-forming component (matrix) can be considered plant or wood waste with a lignin extracted during compression, which holds reinforcement components in the form of fillers (coal, household waste, etc.). In addition to increasing the density and heat of combustion of such CMB, it can be expected of its higher resistance to abrasion and destruction, which is important for the conditions of transportation, storage and movement in the elements of the power plant.

2 SUBSTANTIATION OF THE METHOD FOR PREDICTING EFFECTIVE CONSTANTS OF ELASTICITY OF COMPOSITE BIOFUELS

There are two alternative approaches to determine the elastic characteristics of composite material.

In the experimental approach, a certain structural element of the composite is investigated, the one which contains a sufficiently large number of reinforcing particles so that the results obtained for it could be generalized to any volume of composite material.

Application of this approach allows taking into account the change of elastic properties of the matrix and reinforcing fibers in the process of composite manufacturing. But in order to obtain a composite with the necessary properties it is necessary to conduct a large number of experiments, changing such parameters as the volume content of reinforcement, the nature of the location of reinforcing elements, the use of different materials for the matrix and reinforcing fibers. Therefore, such studies are carried out to refine theoretical models, or when the development or calculation of the latter is too complicated.

An alternative structural approach is the determination of the EEC of the composite through the elastic characteristics of the matrix and reinforcing material, their volume fractions in the composite, the dimensions and relative arrangement of reinforcing elements. A significant disadvantage of such an approach is that the elastic properties of structural components may differ significantly in the initial state and in the composition.

Also determining the value of the effective elastic coefficients of composite materials can be relevant by solving inverse problems of mathematical physics [15], as specific tasks where the desired variables are factors relevant model equations and the area where these equations are defined.

The most researched in the theory of composites and widespread in practice composite materials are materials with fibrous structure [16], to which CMB can be referred.

To determine the effective elastic characteristics in the mechanics of such CM there are various micro-mechanical methods of predicting the elasticity constants of fiber composites, based on a number of hypotheses and assumptions and allow us to consider the material in the CM layer transversal-isotropic [17].

In [18], the determination of the effective characteristics of unidirectional fibrous CM by structural parameters of material components is considered on the basis of known micromechanical models for the prediction of physico-mechanical constants. These include models: Hill, Kilchinsky, Hashin-Rosen, Vanin, Reuss-Voigt.

According to Hill's model, the composite consists of a fiber that is in a coaxial matrix cylinder [18-20]. In the model of Kilchinsky [15, 18, 21, 22], Hashin-Rosen [15, 18, 20, 22] CM is considered as a fiber in the form of a cylinder, which is placed in a cylindrical shell – a matrix, which in turn is in an unbounded medium with elastic parameters equal to the effective parameters of the composite. Model Vanin [21] is used to determine the effective mechanical characteristics of unidirectional composites.

Model Reuss-Voigt [20, 22, 23] is used for composite, the structure of which can be considered as a system of rigidly bound isotropic rods, evenly arranged in an isotropic matrix. This model is in good agreement with the model of the composite biofuel structure chosen above, which makes it possible to calculate the elastic constants of CMB.

According to this model, a certain composite is matched with a homogeneous medium, for which elastic characteristics must be determined. We believe that Young's modules E_1, E_2 and Poisson's ratios ν_1, ν_2 of the two-component composite biofuel granule are known. The ratio of components is characterized by volume concentration $\gamma_1 = V_1/V$, where V_1 - the volume of the first component, V - the volume of the whole granule.

According to the Reuss-Voigt model, the shear modulus μ and compression modulus K satisfy the following inequalities:

$$\mu_\mathrm{r} \le \mu \le \mu_\mathrm{v},\ K_\mathrm{r} \le K \le K_\mathrm{v}, \tag{1}$$

where μ_r and μ_v are the shear modules of Reuss and Voigt respectively; K_r and K_v are the compression modules of Reuss and Voigt respectively.

The Reuss and Voigt modules are defined through component modules using the following formulas:

$$\mu_v = \gamma_1\mu_1 + (1-\gamma_1)\mu_2, \quad \mu_r = \frac{\mu_1\mu_2}{(1-\gamma_1)\mu_1 + \gamma_1\mu_2}, \tag{2}$$

$$K_v = \gamma_1 K_1 + (1-\gamma_1)K_2, \quad K_r = \frac{K_1 K_2}{(1-\gamma_1)K_1 + \gamma_1 K_2}. \tag{3}$$

The intervals of possible values of the effective modules, which are set by formulas (1) - (3), are often quite large.

In some cases, these intervals can be significantly reduced by using the variational principle of the Hashin-Strickman model [24, 25], which is developed for investigate inhomogeneous elastic materials based on the generalization of the Lagrangian variational principle. Together with the inhomogeneous body that is studied, some homogeneous elastic body (comparison body) is considered.

On the basis of the Lagrangian, a functional is constructed, which has a minimum in the equilibrium position if the tensor of the elasticity modules of the examined body is "smaller" than the tensor of the elasticity modules of the comparison body and has a maximum in the equilibrium position if the tensor of the elasticity modules is "larger" than the tensor of the elasticity modules of the comparison body. If $K_1 > K_2$ and $\mu_1 > \mu_2$, so, this approach gives the following relations for the shear modulus and compression modulus:

$$\mu_{\text{h}} \le \mu \le \mu_{\text{s}}, K_{\text{h}} \le K \le K_{\text{s}}, \tag{4}$$

where μ_{h} and μ_{s} are the shear modulus of Hashin and Strickman, respectively; K_{h} and K_{s} are the compression modules of Hashin and Strickman, respectively, which are defined:

$$K_{\text{h}} = \frac{K_1 K_2 + \frac{4}{3}(1-\gamma_1)\mu_2 K_2 + \frac{4}{3}\gamma_1\mu_2 K_1}{K_1 + \frac{4}{3}\mu_2 - \gamma_1(K_1 - K_2)}, \tag{5}$$

$$K_{\text{s}} = \frac{K_1(K_2 + \frac{4}{3}\gamma_1\mu_1 K_2) + \frac{4}{3}(1-\gamma_1)\mu_1 K_2}{K_1 + \frac{4}{3}\mu_1 - \gamma_1(K_1 - K_2)}, \tag{6}$$

$$\mu_{\text{h}} = \frac{5\gamma_1(\mu_1 - \mu_2)(3K_2 + 4\mu_2)\mu_2}{5(3K_2 + 4\mu_2)\mu_2 + 6(\mu_1 - \mu_2)(K_2 + 2\mu_2)(1-\gamma_1)}, \tag{7}$$

$$\mu_{\text{s}} = \frac{5(1-\gamma_1)(\mu_2 - \mu_1)(3K_1 + 4\mu_1)\mu_1}{5(3K_1 + 4\mu_1)\mu_1 + 6(\mu_2 - \mu_1)(K_1 + 2\mu_1)\gamma_1}. \tag{8}$$

The shear modulus and compression modulus can be expressed through the Young's modulus and Poisson's ratio [24]:

$$K = \frac{E}{3(1-2\nu)}, \quad \mu = \frac{E}{2(1+\nu)}. \tag{9}$$

The above approaches can be applied to specific composite materials based on solid plant waste. First, it can be determined K_1, K_2, μ_1, μ_2, and then to calculate K_{v}, K_{r}, μ_{v}, μ_{r}, K_{h}, K_{s}, μ_{h}, μ_{s}, using Eqs. (2), (3), (5) - (8). The technical characteristics of the composite material may be based on the arithmetic mean of the corresponding values, namely

$$\mu_{\text{rv}} = \frac{\mu_{\text{r}} + \mu_{\text{v}}}{2}, K_{\text{rv}} = \frac{K_{\text{r}} + K_{\text{v}}}{2}, \quad \mu_{\text{hs}} = \frac{\mu_{\text{h}} + \mu_{\text{s}}}{2}, K_{\text{hs}} = \frac{K_{\text{h}} + K_{\text{s}}}{2}. \tag{10}$$

On the basis of Eq. (9), we obtain backward transition formulas:

$$\nu = \frac{3K - 2\mu}{2(3K + \mu)}, \quad E = \frac{9K\mu}{3K + \mu}. \tag{11}$$

Using the last Eq. (11), can be defined E_{rv}, ν_{rv}, E_{hs}, ν_{hs}.

Table 1 Results of calculations of elastic constants for composite pellets based on plant waste

component 1 / component 2	ν_1 / ν_2	E_1 / E_2	K_1 / K_2	μ_1 / μ_2	K_{h} / K_{s}	μ_{h} / μ_{s}	K_{r} / K_{v}	μ_{r} / μ_{v}	ν_{hs} / ν_{rv}	E_{hs} / E_{rv}
straw	0.124	3158	1400	1405	-	-	2196	1151	-	-
PET	0.41	2750	5093	975.2	-	-	3246	1190	0.312	3071
straw	0.124	3158	1400	1405	1280	1297	1274	1294	0.121	2909
pine tree	0.118	2680	1169	1199	1280	1298	1285	1302	0.121	2909
husk of sunflower	0.125	3441	1529	1529	1463	1466	1462	1464	0.125	3297
straw	0.124	3158	1400	1465	1463	1466	1465	1467	0.125	3296
husk of sunflower	0.125	3441	1529	1529	1338	1353	1325	1344	0.122	3037
pine tree	0.118	2680	1169	1199	1340	1354	1349	1364	0.122	3037
oak tree	0.127	2987	1335	1325	1250	1.26	1247	1259	0.123	2830
pine tree	0.118	2680	1169	1199	1250	1.26	1252	1262	0.123	2829

The Reuss-Voigt model can be applied to any biofuel composite for it can determine the values of the effective elastic coefficients in a wide range, but it can lead to large errors in determining their values.

When calculating the Hashin-Strickman model, one can expect a smaller error in the determination of EEC composite biofuels. However, the range of use of this model is considerably narrower and it can be applied only if conditions $K_1 > K_2$ and $\mu_1 > \mu_2$ are met at the same time. If $\nu_1 = \nu_2$, then from Eq. (9) it follows that the indicated inequalities are guaranteed to be fulfilled at $E_1 > E_2$. If, for example, ν_1 increases with a constant value of ν_2, then this leads to an increase in K_1 and a decrease in μ_1, which in turn leads to a violation of the above conditions. Thus, Hashin's-Strickman's approaches can only be applied when the values of Poisson's ratios of the biofuel composite are close.

Tab. 1 shows the results of calculations of elastic constants of composite biofuel pellets according to the above mentioned models of Reuss-Voigt and Hashin- Shtrickman. Pellets composition was chosen on the basis of common plant wastes.

For calculations of the average values of the elastic constants of composite components were used, because their values given in the literature sources differ significantly for the same materials [3, 4, 26, 27]. In all cases, the value of Young's modulus was set in MPa and taken as $\gamma_1 = 0.5$.

Analysis of the results given in Tab. 1 shows that the calculated values of EEC for composite pellets on the basis of common plant waste obtained from Reuss-Voigt and Hashin-Shtrickman models practically do not differ. Therefore, the application of the Reuss-Voigt model is sufficient for composite biofuels, since its use is possible for a wider range of elastic characteristics of CMB components.

3 METHODOLOGY AND RESULTS OF EXPERIMENTAL STUDIES

The testing machine UIP-50 which was used for experimental verification of the calculation method of elastic constants of composite pellets is universal, and the investigated sample of pellets was located in its working part shown in Fig. 1.

Figure 1 Location of the investigated sample of composite pellets in a universal testing machine

In order to correct possible traction irregularities and remove backlashes in the testing machine load system, a preload of 100 ± 1H was carried out.

Deformation by compression of the specified sample was performed with simultaneous recording of the deformation diagram.

The specimen was compressed and fixed the amount of movement of the moving traverse. Values of the compression force were measured using a force meter, the, which were also displayed on the device for recording the graph of the relationship between the load and the movement of the traverse.

According to the recorded deformation diagrams, the Young's modulus of the sample was determined $E = (P/F)/(\Delta l/l)$, where $\Delta l/l = \varepsilon$ – relative longitudinal deformation; P – compression force applied to the sample; F – cross-sectional area of the sample; Δl – change in the longitudinal deformation of the sample; l – initial height of the sample.

To determine the Poisson's ratio, the geometric dimensions of the samples were measured before and after loading:

$$\nu = \frac{\varepsilon'}{\varepsilon}, \tag{12}$$

where $\varepsilon' = \Delta d/d$ – is the relative lateral deformation; Δd – is the amount of the change in lateral deformation of the sample; d – is the initial diameter of the sample.

Values for determining the relative longitudinal and lateral deformations were measured at the beginning of crack formation on the specimens, which appeared on the peripheral parts of them before the subsequent destruction with the separation of individual material particles.

An electronic control caliper with a measurement value of 0.01 mm was used as a control instrument.

In experiments, samples of two-component pellets consisting of straw (E = 3160 MPa, $\nu_2 = 0.124$ [3]) and brown coal (E = 3020 MPa, ν_1 = 0,3 - dataset for coal [28]) were used for the corresponding γ_1 = 0.1; 0.2; 0.3 These samples were made on the above-mentioned universal testing machine using a special press device. The samples had the sizes d = 27 mm, l = 20 mm, and for their manufacture straw particles with fraction up to 4.0 mm and crushed brown coal with fraction up to 1.0 mm were used.

To evaluate the method of experimental determination of the elastic coefficients of a composite sample on the basis of plant wastes, an experimental determination E and ν of a similar sample (d = 27 mm, l = 20 mm) made of pine was carried out using this method.

The obtained values of elastic coefficients of pine samples (E = 3.85 GPa, ν = 0,4) are satisfactory with the corresponding values of E = 4.0 GPa, ν = 0.45, given in [29].

Results of experimental determination of elastic constants of composite granules samples are given in Tabs. 2 and 3.

Table 2 Results of experimental determination of Young's modulus values of composite pellets

Volume concentration of brown coal	E					ΔE, %
	No. Experiment			E_{av}	By the model Reuss-Voigt	
	1	2	3			
$\gamma_1 = 0.1$	2630	2644	2678	2650.6	3161	16
$\gamma_1 = 0.2$	2809	2848	2858	2838.3	3158	10
$\gamma_1 = 0.3$	3101	3180	3194	3158.3	3150	0.3

* ΔE – deviation of the calculated values from the experimental ones

Tabs. 2 and 3 show the comparative results of experimental studies with the results of the Reuss-Voigt model calculations, since the conditions $K_1 > K_2$ and $\mu_1 > \mu_2$ are not fulfilled for the composite consisting of straw and brown coal, and in this case it does not allow using the Hashin-Strickman model for calculations.

Table 3 Results of experimental determination of Poisson's ratio values composite pellets

Volume concentration of brown coal	ν					$\Delta\nu$, %
	No. Experiment			ν_{av}	By the model Reuss-Voigt	
	1	2	3			
$\gamma_1 = 0.1$	0.120	0.121	0.122	0.121	0.146	17
$\gamma_1 = 0.2$	0.123	0.123	0.124	0.1233	0.167	26
$\gamma_1 = 0.3$	0.144	0.146	0.147	0.1456	0.187	22

*$\Delta\nu$ – deviation of the calculated values from the experimental ones

The analysis of the obtained results shows the satisfactory correspondence of the obtained calculated values of the effective elastic constants of the composite pellets to their experimentally determined values: deviations of Young's modulus value do not exceed 16% and Poisson's ratio 26%.

In [3] on the basis of experimental studies it was shown that Young's modulus for a solid body formed from disperse biomaterials of plant origin, depending on the applied load at the deformation site remained unchanged (error within 5% - 15%). By analogy, the elastic constants can be assumed to be constant for pellets formed from composite material based on dispersed solid plant waste.

The results obtained suggest a considered approach for predicting the effective elastic constants of composite biofuels required for the calculation or selection of press equipment for the production of quality fuel pellets from composites based on solid plant waste.

In the end it should be noted that the values of elastic constants given in the literature sources for the same plant materials may differ significantly [3, 26].

Therefore, the values of the predicted quantities of the EEC of the composite biofuels will significantly depend on the right choice in each case of the quantities of the corresponding coefficients of composite materials components.

4 CONCLUSIONS

It has been suggested to consider fuel pellets made of composites based on solid plant waste as stochastic quasi-systems in which a structural component (matrix) can be considered as plant waste emitting lignin during compression.

The analysis of known micromechanical models for the prediction of physico-mechanical constant composite materials is carried out. To determine the effective elastic coefficients of composite biofuels, the feasibility of using the Reiss-Voigt and Hashin-Strickman models, the conditions of use of these models and the EPC of two-component pellets containing distributed plant waste were calculated.

Experimental estimation of the values of the effective Young's modulus and the Poisson's ratio for pellets of the "straw + brown coal" mixture was performed. Comparison of experimental and analytically determined values of the coefficients of elasticity showed that the deviations for the Young's modulus are in the range up to 16% and for the Poisson's ratio in the range up to 26%.

The results obtained allow recommending the considered approach to predict the effective elasticity constants of composite biofuel required in the calculation or selection of press equipment for the production of quality fuel pellets from composites based on solid plant waste.

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Original scientific paper

Infrared Printing Technique for the Security Marking of Traceability Certificates for Meat Products

Dražen Crčić, Jana Žiljak Gršić, Denis Jurečić

Abstract: The focus of this paper is the introduction of new security elements into the authenticity of information on documents which concern the traceability of products. This article proposes dual marking using the infrared printing technology, which involves differences between the visible and infrared spectrum and separate detection of certain information with an infrared camera. Each meat product is assigned a unique designation, embedded in the document and hidden from the naked eye, in order to prevent changing, scanning or modifying with currently known techniques. A product receives a certificate with a security approval which carries information about the complete traceability of the product. A new central data registry which collects information from all necessary sources is proposed. The web portal and the accompanying database are designed to work in the cloud. The security of the exchange of data between the server and the user is ensured. The information about the traceability and the delineation between the visible and infrared hidden are approved and coordinated by the relevant authorities, breeders, distributors and sellers. The design of the entire information presents completely transparent information about the products to the end consumer.

Keywords: central data registry; Certificates of Traceability; INFRAREDESIGN; near infrared spectrum; security marking

1 INTRODUCTION

The packaging of a product is loaded with information about the product, quality, method of application and other possible legally required elements. Designers have to find space for a lot of data on the packaging of a certain product.

Conventional security print products involve the use of ultraviolet and infrared colorants and papers with security properties, such as a watermark, embedded threads or finishing with foil printing or relief printing. All these techniques increase the cost of the graphic product and are performed in specially authorized printing offices. The emergence of forgeries and attempts at imitation of the existing security technologies are the sign than these conventional techniques are outdated and that new solutions for security printing are needed. This article proposes the INFRAREDESIGN® technology, which is expanded into individual design though the use of line computer graphics. The IRD CERTIFICATE includes a high level of planning for the hidden information on the packaging. The hidden information is implemented together with other graphic elements in the same printing process for the graphic product. The contribution to security printing is in the design with dual images embedded within each other [1]. This kind of printing technology does not raise the cost of the printing product.

The hidden information is detected with an infrared camera, infrared photo camera or security cameras, such as those that surround us in cities and in stores [2]. These cameras show the hidden image, code or individual marking, none of which can be scanned or photocopied. The system includes the INFRAREDESIGN patent for the individualization of documents during the printing phase and within the information system which creates the packaging.

IRD protects the product and the producer, can be integrated without changing the existing design, i.e. the product registration, and can be applied to all necessary materials. One of the advantages is that the protection is created in the same process as the packaging for the product or the part of product we want to identify.

2 INFORMATION ON THE TRACEABILITY DOCUMENT

There are official programs for the digital record of all these processes, usually determined by the relevant ministries. It is very difficult or even impossible to determine the complete traceability of the origin of meat products in one place. The technologies of traceability of meat products vary in the information provided and in the security marking. This is due to the fact that different programs for different stages of rearing are not connected with each other and do not cover all the processes up until the packaging. There is no one document or one procedure for recording data about the traceability of the production and the product. The final label on the product provides only superficial information about the origin of the product.

Unambiguous security marking of meat on its path from the slaughterhouse to the retail stores is proposed. Currently in this segment only general data and LOT numbers are used, which cannot unambiguously determine the detailed origin of a certain product.

The new central data registry (SMP) collects and consolidates data which confirms traceability in one place. The data is exchanged through the internet – through security https protocol and an additional communication key. This ensures the complete safety of data exchange through a public network. The current registry of information is partial. The tracking of animals and their identification numbers is only done by farmers and slaughterhouses. The data is located in the data registries of the Croatian Agricultural Agency (HPA). Tracking is currently not conducted at the time of packaging. Therefore, it is necessary to ensure that SMP collects additional information about the packaging. This information contains the unique packaging number and the corresponding animal identification number. The new central registry can collect this data in two ways:

- automatically through program integration with the HPA registry,
- manually by farmers, slaughterhouses and packaging companies, who send all locally processed data to the new central registry.

A separate module has been developed for the manual transfer of data. It is run as a web application through an internet browser. The user receives access data and uploads data. The module performs an automatic conversion of the data structure in order to save them in the SMP.

Each product on retail shelves would get its own universal designation. Products would be marked with QR codes [3]. The universal code has a link to the SMP database. The universal code also contains the information about the company and the date of packaging.

Consequently, all information about the meat product can be accessed through the universal designation and previously collected information. The information is available on a separate SMP web portal. The access to information is protected with security protocols and can be given only to designated persons.

If the products are finished, imported products, the data will not contain all the information. However, if the rearing was partially or entirely conducted in Croatia, the information would contain all other data. Through the product designation, which would be visible on the packaging, the following parameters can be accessed:

Packaging label: 7295650472-1583485950-73913-2
Markets: Company xxx
Type of meat: Beef
Born: 05/02/2018 Romania
Breed: Crossbreeds
Life number: RU 234123678
Fattened: 12/03/2018 - 23012020 Croatia (Farm xxx)
Date of slaughter: 01/24/2020 Croatia
Slaughterhouse mass: 247 kg
Packing Date: 01/24/2020
Use up to: 02/10/2020 (BEEF)

The unique designation of the product is generated by using four parameters. The first parameter is the designation of the packaging company. The second parameter is the time of packaging according to the "Unix time" (the number of seconds elapsed since 01/01/1970). The third parameter is a random number, and the forth is a control mark. The program code stated below represents the algorithm for generating a unique designation. The code is made for the PHP programming language. It can be used as an addition to the current program solutions in the packaging process or as a separate module. It is the principal link between the product designation and the traceability of the product.

```
$id = $_GET["company_id"];
$unix_time = time();
$rand = sprintf("%05d", rand(1, 99999));
$main_string = $id.$unix_time.$rand;
$luhn = new Luhn();
$k = $luhn->calculate($main_string);
$oznaka = $id."-".$unix_time."-".$rand."-".$k;
```

3 INFRAREDESIGN OF DUAL EMBEDDED GRAPHICS

The implementation of IRD documentation would bring multiple benefits. End consumers would have detailed information about the origin of the product. Complete reports would enable the authorities to better track and control production and distribution. Origin control would be greatly simplified. Every company that conducts the packaging of products is required to send the new designation and the animal identification number to the central data registry. This makes it possible to determine for every product: where the animal was born, what farm(s) it was reared at and when and where the meat was classified.

With the IRD certificate, each product on store shelves receives its own, innovative, universal sign. Products are marked with dual QR codes with additional IRD protection [3]. A design with two different QR codes is printed in one spot. Within the code for the visible spectrum the QR code is embedded read on the screen of the camera for the infrared light spectrum. The security of information in both codes is achieved. The implementation of (paper) IRD documents would bring multiple benefits. IRD documentation is used in two forms. The first use is for manual input of information collected for the central register, i.e. for the internet database. The second use is for the end user when he or she receives the packaged product.

The line graphics have curved elements at the edges of the letters "TYPE OF MEAT: BEEF". The oblique line covers more space, causing the effect of typography recognition. The certificate is transparent and only 60% of its surface is covered with color. The colors in the curved lines vary based on a linear congruential generator with a six-digit seed and a modulus of integer values. The second image from the IRD plan, invisible to the naked eye, will be recorded with a camera for the infrared spectrum. The initial image is a continuous photograph. By combining it with curved line graphics, the hidden image will appear only in parts of the image (Figure 4). Positive gray values exist only where there are twin colorants defined in curved line graphics – in other words, only where the replacement of process colorants cyan, magenta and yellow with the carbon black color according to the method of VZ separation (the special part of GCR/Gary Color Reduces process) is possible.

For the purposes of this article, the recipes for twin colors for the carbon black color with 40% coverage on polypropylene material (1) have been experimentally calculated. In our lab, the experimental plan covers between 80 and 120 recipes for twin colorants. Some printing techniques and their corresponding color tones require many experiments, which include the examination of the dependence of the layer thickness of a specific process color, transparency, the type of the raster form [4] and the common property of light absorption. The results (with the condition of $\Delta E<3$) of different recipes for color tones are shown as a regression equation of the dependence of X_{40} on X_0 [1]. The reduction of every C, M, Y colorant in X_{40} shows a mutual dependence on the other two colors from X_0 [1].

$$\begin{aligned} C40 &= -0.0222*Y - 0.175*M + 1.244*C - 30.3 \\ M40 &= -0.055*Y + 1.105*M + 0.133*C - 34.1 \\ Y40 &= 1.124*Y - 0.0802*M + 0.0172*C - 33.2 \end{aligned} \tag{1}$$

For the first five colors (Fig. 1) of the first five curved lines the values are given from relation (1) in Tab. 1. Model (1) can serve for some other plans, provided that the parameters in the equations are valid for digital printing with toner on a transparent material.

Table 1 Recipe for the first five twins according to model (1):

	X0: C,M, Y, K=0	X40: C, M, Y, K=40	Difference X0 – X40	
1.	51, 95, 79, 0	15, 73, 49, 40	36, 22, 30	
2.	95, 54, 51, 0	76, 35, 21, 40	18, 18, 30	
3.	61, 44, 82, 0	36, 18, 56, 40	25, 26, 26	
4.	85, 73, 90, 0	61, 53, 64, 40	24, 20, 26	
5.	58, 62, 44, 0	30, 40, 12, 40	28, 22, 32	

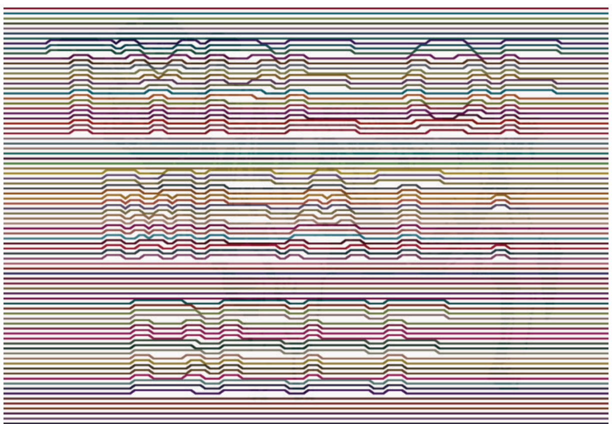

Figure 1 Light blockade at 400 nm

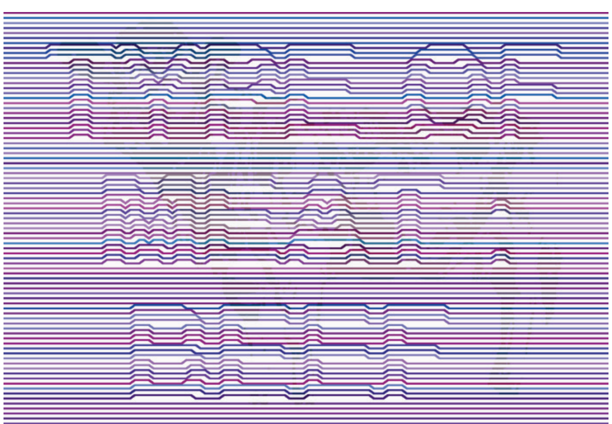

Figure 2 Light blockade at 550 nm

The colors in the lines gradually disappeared through filtering: yellow at 550 nm, magenta at 650 nm and cyan at 780 nm [5]. The continuous changes of light filtering are observed and detected with an animation given at: jana.ziljk.hr/beef.mp4 [6], where the images from 24 light blockades from the visible and near-infrared spectrum between 400 and 1000 nm were combined [7].

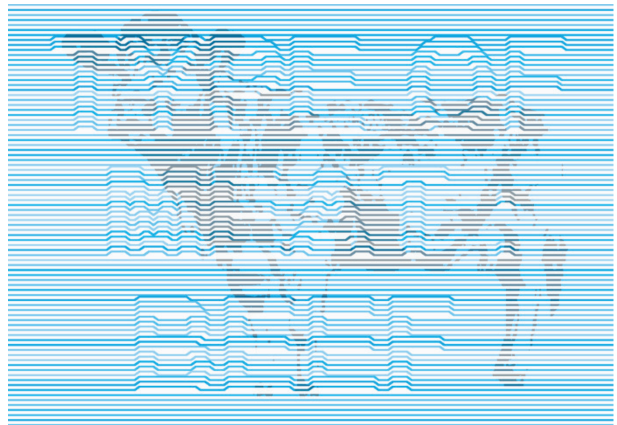

Figure 3 Light blockade at 700 nm

Figure 4 Light blockade at 1000 nm

The security video animation shows the appearance of the hidden image already at 650 nm, but this image can never become the basis for creating a new, falsified dual image. The proposed innovation is the combination of computer graphics as curved lines which select the information of the hidden image. Our eyes see the imprint identical to the blockade at 400 nm (Fig. 1), just as an RGB photography does. The photograph with the Z camera is identical to Fig. 4.

4 DISCUSSION AND CONCLUSION

Infrared intrigues with its simultaneous visibility and invisibility and opens up entirely new possibilities unimaginable prior to its invention. This invention arouses interest and offers numerous possibilities for graphic design solutions. IRD motivates us to think about the application in the system of protection against counterfeits.

The hiding of the information in order to protect the packaging is ensured in the infrared and visible spectrum. Authenticity is proved using spectral analysis of colorants on the graphic product. IRD brings innovation in the design of packaging and the protection against copying. Photocopying machines do not recognize the Z spectrum (1000 nm) in the infrared area or the technology of the separation of two pieces of information which are physically in the same place. IRD opens up the possibility of applying hidden barcodes with multi dye twin color for the protection against falsifying. These codes would also be invisible to the naked eye and detectable only with a camera for the infrared spectrum.

The new central data registry (SMP) collects data from all the necessary databases and sources. The SMP is in the cloud. The data is exchanged through the internet – through security https protocol and an additional communication key. This ensures the complete safety of data exchange. JSON structure of data with REST API methods is used.

Infrared certificates serve as receptacles. They are physically organized information which gives the end user an additional sense of security concerning the information about the traceability of products.

Information about the traceability would be provided as needed to relevant authorities, breeders, distributors and sellers. It is also possible to present the whole information to end consumers as completely transparent information about the sold products.

This would increase the visibility of Croatian farmers. There is a problem in certain parts of the industry – the differences between the quality of meat of animals born and reared outside of Croatia and the quality of meat of animals born outside of Croatia and those entirely reared in Croatia are not sufficiently recognized. With transparent information about the traceability, such differences would immediately be recognized.

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[6] Animation: https://jana.ziljak.hr/beef.mp4, https://jana.ziljak.hr/beef.swf

[7] Projectina Docucenter 4500, SP-2000 color spectroscopy module & PAG B50 custom designed with 24 barrier filters; http://forensictechnology.com/projectina/

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Original scientific paper

A Novel Coplanar Waveguide-Fed Compact Microstrip Antenna for Future 5G Applications

Mustafa Berkan Bicer

Abstract: In this study, a coplanar waveguide-fed compact microstrip antenna design for applications operating at higher 5G bands was proposed. The antenna with the compact size of 8 x 12.2 mm² on FR4 substrate, having the dielectric constant of 4.3 and the height of 1.55 mm, was considered. The dimensions of the radiating patch and ground plane were optimized with the use of artificial cooperative search (ACS) algorithm to provide the desired return loss performance of the designed antenna. The performance analysis was done by using full-wave electromagnetic package programs based on the method of moment (MoM) and the finite integration technique (FIT). The 10 dB bandwidth for return loss results obtained with the use of the computation methods show that the proposed antenna performs well for 5G applications operating in the 24.25 – 27.50 GHz, 26.50 – 29.50 GHz, 27.50 – 28.35 GHz and 37 – 40 GHz frequency bands.

Keywords: compact microstrip antenna; coplanar waveguide-fed; microstrip antenna design; planar antenna; 5G applications

1 INTRODUCTION

Recently, the rapid development of systems such as short-range communication, online music and video services, smart systems, health diagnostic and treatment devices, and the internet of things (IoT), which require high-quality voice, video and data access with high speed, has led researchers to research and develop fifth-generation (5G) mobile communication technologies [1, 2, 11-19, 3-10]. It is foreseen that the need for mobile traffic in the coming years will be much higher than the amount needed today. 5G mobile communication technology enables high-speed data transfer covering wide areas and meets requirements such as high capacity, security, and reliability, allowing to reduce latency and power consumption. 5G technology, which is among the most important developments of recent years, is thought to provide development in many fields such as economic development, education, health, defense, transportation, and energy systems [1, 2, 11-19, 3-10]. Electronic devices such as refrigerators, air conditioners, ovens, air conditioners, and other digital services in daily use will become remotely manageable thanks to 5G technology. Since it has such a wide range of applications, the frequency spectrum to be allocated for 5G communication is of great importance. 5G is being conducted by various countries and companies in various ranges of frequency spectrum, such as sub-6 GHz spectrum covering 1.427 GHz to 1.518 GHz, 1.69 GHz to 2.2 GHz, 2.30 GHz to 2.69 GHz, 3.30 GHz to 5.00 GHz bands and 24.25 GHz to 27.50 GHz, 26.50 GHz to 29.50 GHz and 37.00 GHz to 40.00 GHz frequency bands. However, due to the low atmospheric absorption rate, it is thought that 5G applications will concentrate mostly on the Ka-band [1, 2, 11-19, 3-10].

Reductions in the size of abovementioned systems necessitate the development of millimeter-wave antennas having both high performance and smaller size [20-23]. Due to their impressive advantages such as low weight and volume, low production cost, small dimensions, planar structure, ease of design and manufacturing, and easy integration with solid-state circuits, microstrip antennas (MA) have been the focus of interest for researchers designing antennas for 5G applications. However, conventional shaped microstrip antennas with triangular, rectangular, and circular configuration have limitations such as low gain and narrow bandwidth. To overcome these limitations, the geometries of the microstrip antennas are modified in various ways to have characteristics such as high gain, wide bandwidth, and multiple resonance frequencies [20-23]. One of the methods used to increase bandwidth is to change the feeding structure of the antenna. Coaxial-fed microstrip antennas have a very narrow bandwidth, whereas coplanar waveguide-fed (CPW) microstrip antennas have a broad bandwidth. In order to provide multiple frequency band performance, making modifications on the radiation geometry and ground plane of the antenna is widely preferred in antenna design. The microstrip antennas obtained by making modifications on the geometries of conventional-shaped antennas are called as compact microstrip antennas (CMA). The analysis of CMAs is complicated due to the complexity of their structures, and computer-aided full-wave electromagnetic computation software based on the techniques, such as finite element method (FEM), finite integration method (FIT), finite difference time domain (FDTD) and method of moments (MoM), is needed to perform the required calculations [24-26]. The performance of microstrip antennas operating at high frequencies is severely affected by the change in physical dimensions. Therefore, artificial intelligence optimization techniques are used in the design of antennas that can meet the desired performance criteria. In the literature, there are studies related to CMA design using optimization techniques such as artificial bee colony (ABC) [23, 27-29], ant colony optimization (ACO) [30-32], differential evolution (DE) [33-35], genetic algorithm (GA) [30, 31, 34, 35] and particle swarm optimization (PSO) [34, 35]. Jian et al. [36] designed an antenna using a hybrid optimization algorithm, particle swarm ant colony optimization (PSACO) algorithm, operating at the center frequency of 28 GHz. They verified the reliability of the PSACO that they used to optimize the antenna's dimensions with the use of Elman Neural Network (ENN) model. Akdagli and Ustun [37] designed a microstrip-fed rectangular microstrip antenna with a modified ground plane using the new hybrid optimization algorithm that they proposed using the ABC and DE algorithms. The outer dimensions of the proposed antennas vary between 19.20 × 16 mm^2 and 62.21 × 51.90 mm^2. In another study of Jian et al. [38], a millimeter-wave antenna was designed using a new hybrid optimization algorithm with the imperial competition algorithm (ICA) and ant colony algorithm (ACO), operating at a frequency of 28.5 GHz.

This paper aims to propose a coplanar-wave guide (CPW) fed compact microstrip antenna for future 5G applications. The designed antenna has a low profile with the volume of 8 × 12.2 × 1.55 mm^3 and operating between 24.14 GHz – 32.40 GHz and after the 33.72 GHz. To achieve the best performance characteristics for 5G applications, the optimization process of the proposed antenna dimensions is performed using the ACS algorithm, and the FIT technique is utilized for the simulation and performance analysis of the antenna. The obtained antenna has compact dimensions and can be used for mobile applications.

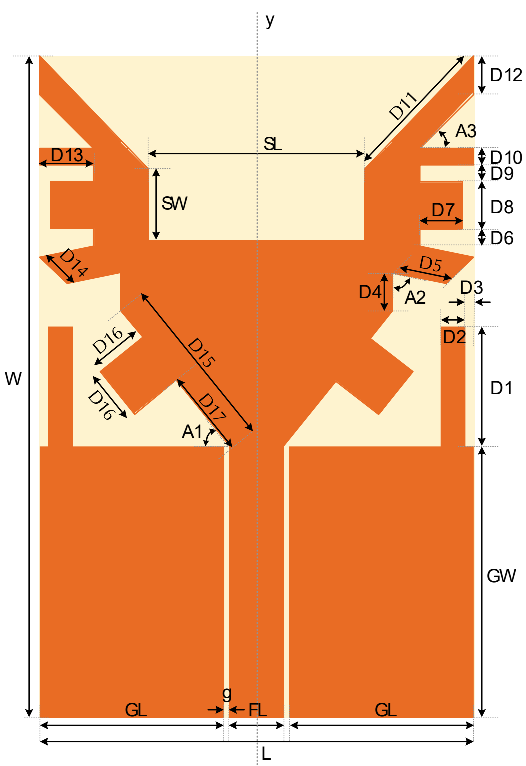

Figure 1 Top view of the proposed antenna

2 ANTENNA DESIGN

The presented antenna for 5G applications, operating in the range of the 24.25 – 27.50 GHz, 26.50 – 29.50 GHz, 27.50 – 28.35 GHz, and 37 – 40 GHz frequency bands, is shown in Fig. 1. As shown in the figure, the antenna has symmetrical radiating branches on both sides of the trapezoidal radiating patch, and both ground planes modified by adding thin rectangular elements. The proposed antenna is fed with a 50 Ω SMA connector. Initially, the sizes of the radiating arms determined considering the wavelengths of each frequency. Subsequently, the dimensions are optimized to give the desired performance criteria related to 10 dB bandwidth for return loss.

The values of the physical parameters of the antenna, shown in Fig. 1, are given in Tab. 1.

Table 1 Physical dimensions of the proposed antenna (in mm)

D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
2.21	0.44	0.16	0.70	1.02	0.31	0.81	0.87	0.31
D10	**D11**	**D12**	**D13**	**D14**	**D15**	**D16**	**D17**	**L**
0.30	2.89	0.70	1.00	0.71	3.20	1.00	1.57	8.00
W	**GL**	**GW**	**SL**	**SW**	**g**	**A1**	**A2**	**A3**
12.20	3.40	5.00	4.00	1.31	0.10	51.34°	78.69°	45.00°

A coplanar waveguide feeding structure is used to feed the designed antenna. The lengths of the microstrip feeding line and the ground planes are 1 mm and 3.4 mm, respectively, while the widths of both ground planes and microstrip line are 5 mm. The length of the gap between the microstrip line and the ground planes is taken as 0.1 mm. The radiating patch, microstrip line, and ground planes are placed on the top side of the FR4 substrate having the dielectric constant of 4.3, the height of 1.55 mm and the loss tangent of 0.02. The antenna is entirely symmetrical concerning the *y*-axis.

3 ANTENNA OPTIMIZATION

The resonance frequency for an antenna operating at TM_{mn} mode is given by Eq. (1) [39].

$$f = \frac{c}{2\sqrt{\varepsilon_{\text{eff}}}}\sqrt{\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2} \quad (1)$$

In Eq. (1), f, c, ε_{eff}, L and W parameters represent the resonant frequency of the antenna, effective dielectric constant, length of the antenna and width of the antenna, respectively, while m and n parameters represent the operating mode of the antenna. The effective dielectric constant value in Eq. (1) is calculated by the formula given in Eq. (2) [39, 40].

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{1 + 12\frac{h}{W}} \quad (2)$$

where εr and h represent the dielectric constant value of the substrate and the height of the substrate, respectively. As seen in Eq. (1) and (2), the operating frequency of an antenna mainly depends on the dielectric constant of the material and the physical dimensions of the radiating patch. Since the height of the substrates that can be used to fabricate the antenna is standard, the dimensions of the antenna elements should be optimized to achieve the desired bandwidth characteristic. The bandwidth characteristic of an antenna is determined by the return loss graph, which is generated by calculating the formula given by Eq. (3) for each frequency [39].

$$RL = -20\log\left(\frac{z_L - z_0}{z_L + z_0}\right) \quad (3)$$

where z_L and z_0 represent the characteristic impedance of the antenna and the free space, respectively. As given in Eq. (3), the return loss represents the degree to which the antenna impedance is in agreement with the free space impedance. In this study, since the antenna is fed through a single port, the return loss value is considered only for S_{11}. In order to say that the designed antenna performs well in the desired frequency band, the bandwidth characteristic of the antenna should be below −10 dB reference level. Accordingly, the cost function for the desired performance should be set so that the parameter S_{11} is below −10 dB. The cost function used in the optimization process of the proposed antenna is given in Eq. (4).

$$CF = \frac{1}{N}\sum_{n=1}^{N} C\left(f_n\right) \quad (4)$$

$$C = \begin{cases} 0, & S_{11,\text{ calculated}} < S_{11,\text{ desired}} \\ \left|S_{11,\text{ desired}} - S_{11,\text{ calculated}}\right|, & \text{otherwise} \end{cases} \quad (5)$$

The C conditional cost term, used in Eq. (4), is given in Eq. (5). N, $S_{11,\text{ calculated}}$ and $S_{11,\text{ desired}}$ parameters represent the count of the desired frequency points, calculated S_{11} parameters obtained with the help of the computational methods and desired S_{11} values, respectively.

4 ARTIFICIAL COOPERATIVE SEARCH ALGORITHM FOR DIMENSION OPTIMIZATION

Artificial Cooperative Search (ACS) is a swarm-based optimization method that depends on the movement of two biologically interacting artificial superorganisms to obtain the global minimum value of the real-valued numerical optimization problem [41]. The amount of food that can be obtained from a particular region in nature is susceptible to seasonal climate changes. Due to this, some of the superorganisms migrate seasonally between different feeding regions. Superorganisms with such migration behavior are capable of moving from a living habitat with a decrease in the quantity and diversity of reserves it offers to a more fertile environment. In most species, the large number of members coalesce to form a superorganism before journey. Then, the more productive regions of the superorganism begin to migrate. Before migration, superorganisms can be divided into sub-superorganisms. Under these conditions, the coordination of the sub-superorganisms determines the behavior of the superorganisms [41].

In the ACS method, a superorganism, which consists of arbitrary solutions to the dilemma, corresponds to an artificial superorganism that migrates to further efficient nutrition spaces. The ACS method is form on two superorganisms defined as α and β, which are artificial sub-superorganisms equal to the size of the community, N. These sub-superorganisms hold as many individuals as the size of the problem, D. In the ACS, artificial sub-superorganisms, *Predator* and *Prey*, are detected using α and β superorganisms. *Predator* sub-superorganisms in the method can track *Prey* sub-superorganisms for some time while migrating to the global minimum level [41].

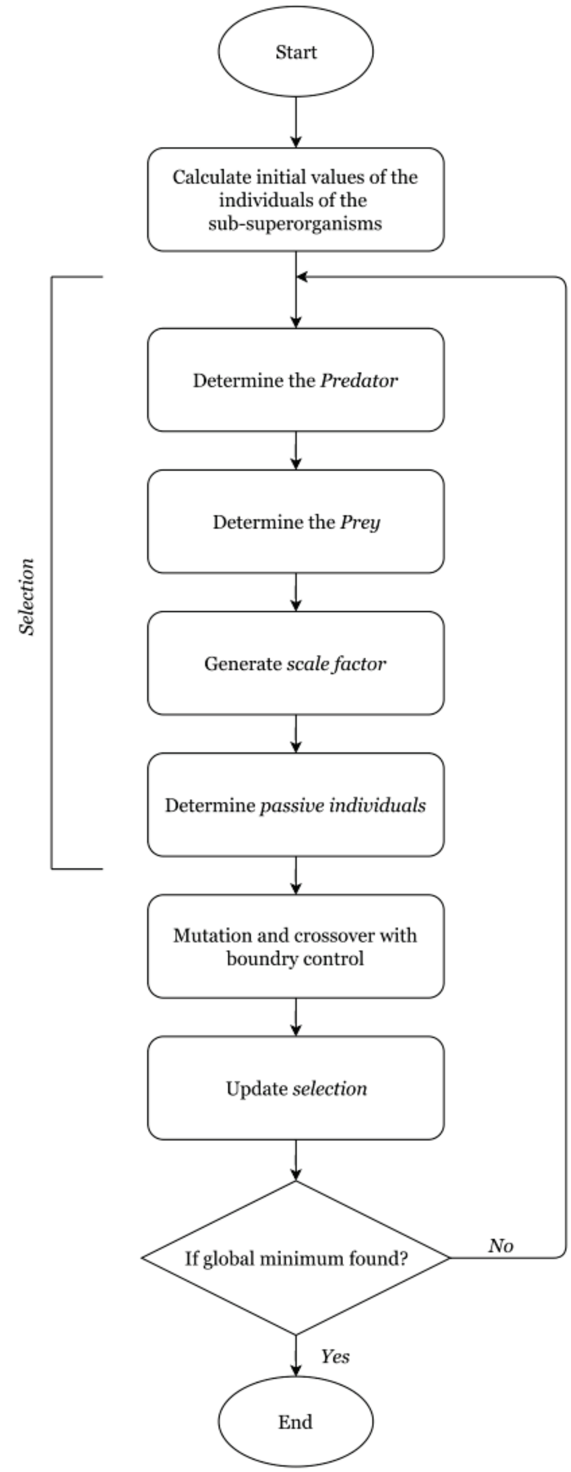

Figure 2 The flowchart of the ACS algorithm

The individuals of i^{th} sub-superorganism of the two superorganisms take the values determined by the Eq. (6) and (7) as initial values.

$$\alpha_{i,j,g} = rnd \cdot \left(up_j - low_j\right) + low_j \tag{6}$$

$$\beta_{i,j,g} = rnd \cdot \left(up_j - low_j\right) + low_j \tag{7}$$

where $i = 1, 2, \ldots, N$ and $j = 1, 2, \ldots, D$ while $g = 0, 1, 2, \ldots, maxcycle$. The variable g stands for the iteration number, called *coevolution*, and *rnd* is the random number chosen from the uniform distribution in the range of [0 1]. The upper and lower limits of the j^{th} dimension are defined by the variables *of* up_j and low_j.

The fitness values calculated by the sub-superorganisms are given by Eq. (8) and (9).

$$y_{i,\alpha} = f(\alpha_i) \tag{8}$$

$$y_{i,\beta} = f(\beta_i) \tag{9}$$

Since this study is on antenna design and optimization, the rest of the algorithm is given in Fig. 2 with the flowchart. Detailed information about the algorithm is available in the literature [41].

5 NUMERICAL RESULTS

The antenna dimensions are optimized by the help of artificial cooperative search (ACS) algorithm. The computations related to the antenna, which is designed according to the obtained dimensions, were made by the full-wave electromagnetic solvers based on the moment method (MoM) and finite integration technique (FIT). The return loss curves of the designed antenna are shown in Fig. 3.

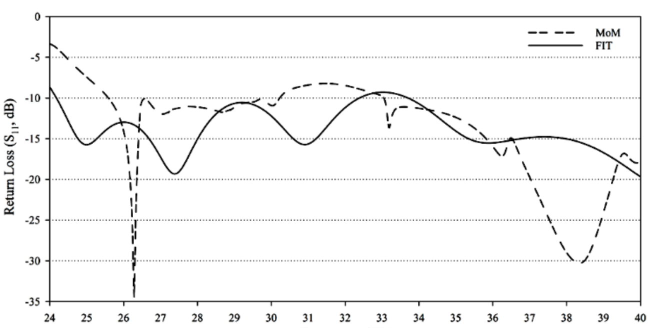

Figure 3 The comparison of the return loss curves obtained by the method of moments (MoM) and finite integration technique (FIT)

As can be seen from the figure, the return loss of the designed antenna is actually below the resonance reference value of −3 dB, where more than half of the incident power is radiated, throughout the desired frequency band. However, the radiation of more than 90% of the indicated power shows that the antenna performs well. According to the return loss result obtained by the MoM, it can be said that the antenna performs well in the range of 25.58 GHz – 30.24 GHz and after the 33.04 GHz frequency. In the frequency band up to 25.58 GHz, the antenna operates but cannot provide the higher performance. When the return loss values obtained by the FIT technique are considered, it can be said that the antenna performs well between the 24.14 GHz – 32.40 GHz range and after the 33.72 GHz frequency. Although there are discrepancies between the return loss results obtained by two methods around the frequency of 24 GHz, the curves are in a good agreement with each other approximately 26 GHz and later. Although most of the existing substrates perform well for the applications operating under the 10 GHz frequency, they experience performance degradation for the mm-wave band due to dielectric loss and dispersion. In this sense, the performance loss can be experienced for inadequate quality FR4 substrate. The radiated power ratio curves are given in Fig. 4.

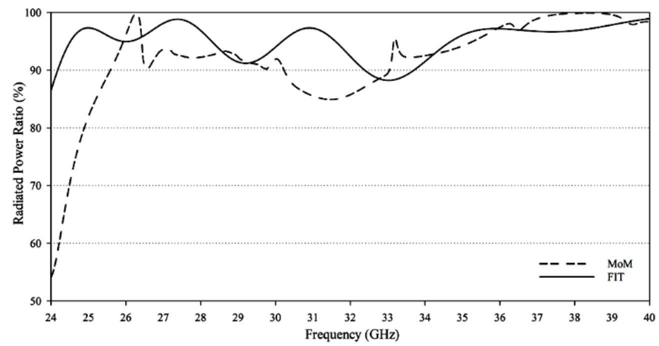

Figure 4 The comparison of the radiated power ratio curves obtained by the method of moments (MoM) and finite integration technique (FIT)

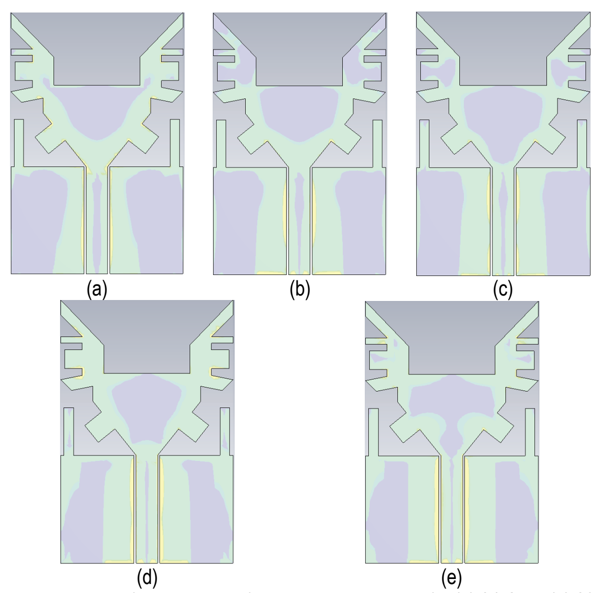

Figure 5 The surface currents of the designed antenna for (a) 24 GHz, (b) 28 GHz, (c) 32 GHz, (d) 36 GHz and (e) 40 GHz

As it is seen from the radiated power curve obtained from the MoM, approximately 54.14% of the incident power is radiated at the 24 GHz frequency, and 57.40% of the incident power is radiated at the 24.15 GHz frequency. However, it is seen from the figure that more than 80% of the incident power is radiated to the air. According to the FIT, approximately 86.52% and 89.71% of the incident power are radiated at the 24 GHz and 24.15 GHz frequencies, respectively. The curve shows that the designed antenna radiates more than 90% of the incident power throughout the desired frequency band.

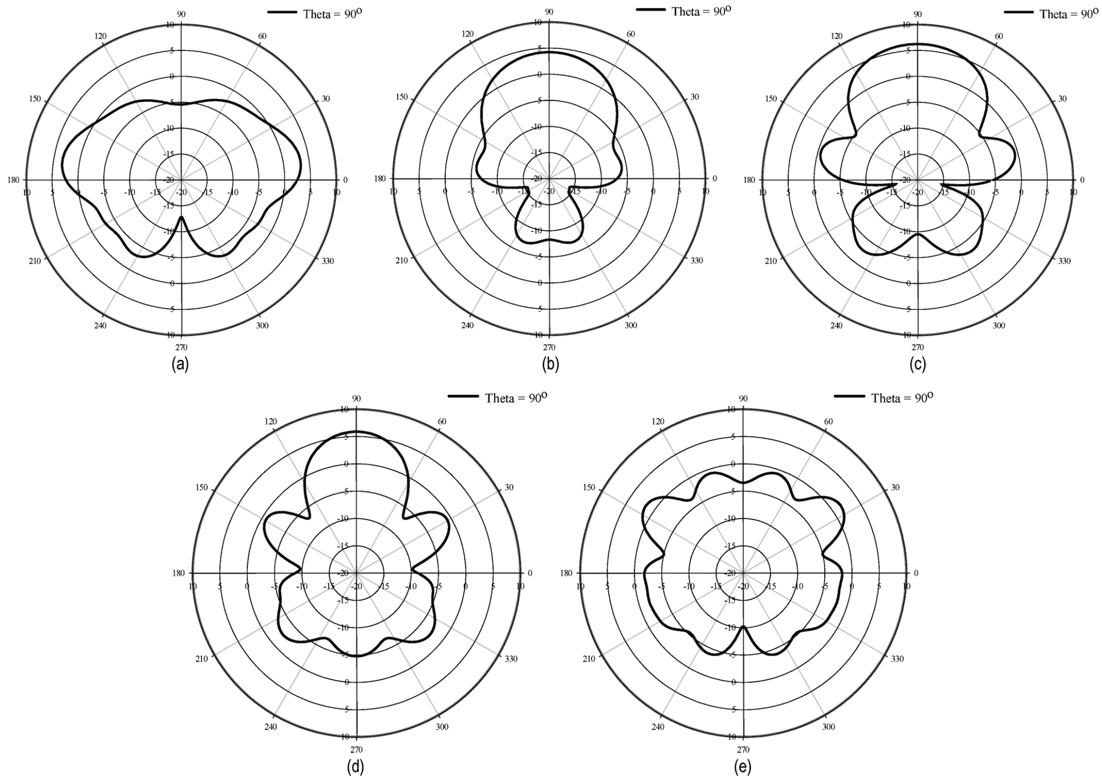

Figure 6 The simulated radiation patterns of the designed antenna for azimuth, Θ = 90°, at (a) 24 GHz, (b) 28 GHz, (c) 32 GHz, (d) 36 GHz and (e) 40 GHz frequencies

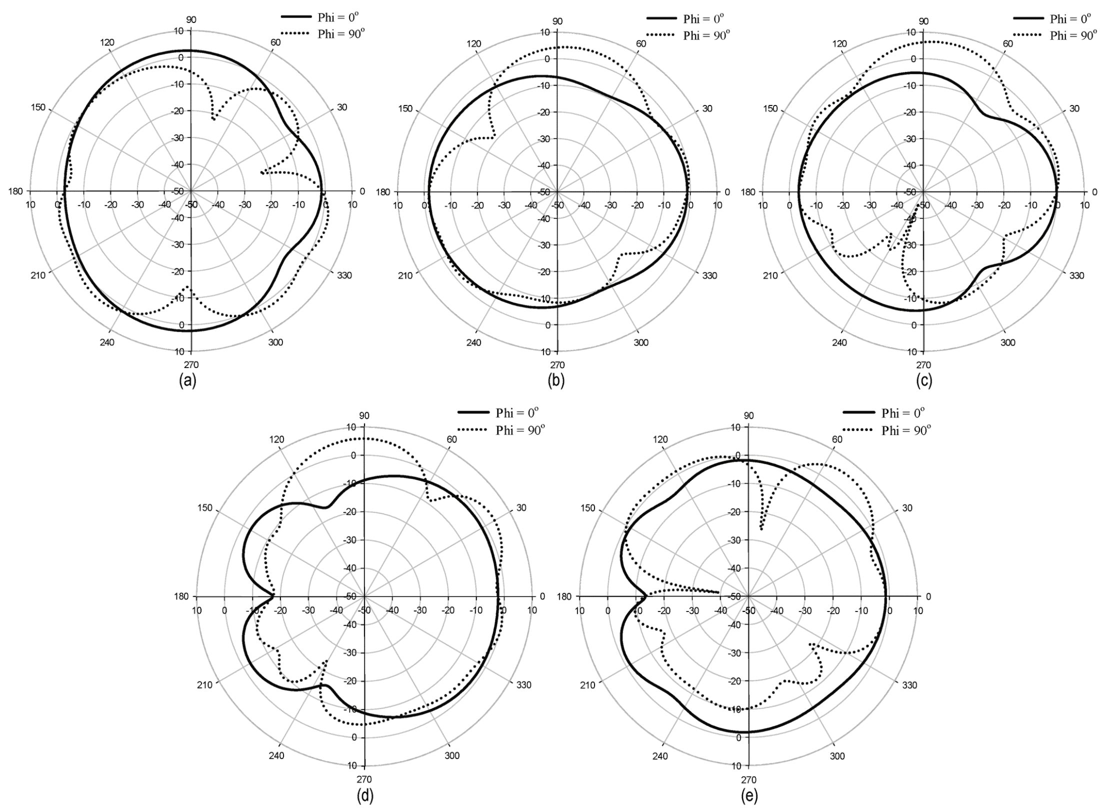

Figure 7 The simulated radiation patterns of the designed antenna for elevation, ϕ = 0° (solid) and ϕ = 90° (dotted), at (a) 24 GHz, (b) 28 GHz, (c) 32 GHz, (d) 36 GHz and (e) 40 GHz frequencies

The figures of the surface currents of the proposed antenna at five frequencies between 24 GHz and 40 GHz are given in Fig. 5.

As can be seen from the figure, surface currents are concentrated at the edges of the radiating patch and the ground planes. The frequencies provided by the arms of the radiating patch can be seen from Fig. 5(a) – 5(e). Also, simulation studies have been carried out on the radiation patterns of the designed antenna. The radiation patterns obtained by simulations are shown in Fig. 6 and Fig. 7. The azimuth plane radiation patterns for five different frequencies in the range of 24 GHz to 40 GHz at $\theta = 90°$ are given in Fig. 6.

The radiation patterns for the azimuth plane of the designed antenna have a weakened shape from the back and sides, as seen from Fig. 6. The radiation is weaker at 270° for 24 GHz, 210° and 330° at 28 GHz, 191° and 348° at 32 GHz, and 270° at 40 GHz frequency but the radiation at almost all frequencies is higher at 90° direction.

Unlike the azimuth plane, the radiation patterns of the proposed antenna for the elevation plane shows almost omnidirectional antenna characteristics, as can be seen from Fig. 7(a) – (e).

6 CONCLUSION

A novel coplanar waveguide-fed compact microstrip antenna for future 5G applications is presented. The proposed antenna design easily achieves the broadband performance required for 5G applications between 24 GHz and 40 GHz frequencies. The antenna with the compact size of 8 × 12.2 mm^2 on FR4 substrate, having the dielectric constant of 4.3 and the height of 1.55 mm, is considered. Afterward, the dimensions of the radiating patch and ground plane are optimized using artificial cooperative search (ACS) algorithm to provide the desired 10 dB bandwidth performance. The results obtained by performing separate simulations of the optimized antenna based on two different methods show that the characteristics of the antenna meet the desired performance criteria. The proposed antenna is thought to be beneficial for patch antenna designers and researchers. The optimized antenna can be fabricated simply by anyone.

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Original scientific paper

A Supplier Selection Model Emphasizing the Project Risk Management in Drug Production in Pharmaceutical Industry

Malek Mohammad Sabbaghi, Ahmad Allahyari

Abstract: Risk management is considered to be one of the main phases of project management and one of the eight main areas of the "project management body of knowledge". The complexities involved in the drug production projects on the one hand, and the need for risk assessment and management in such projects on the other hand, make this issue completely clear. According to the risk mitigation strategies in project management and using the academic professors and experts in the field of drug production and pharmaceutical projects, the present study aimed to provide a checklist for selecting supplier in the drug production projects. This was done using the main eight and 30 secondary indicators related to the top supplier selection and four main and nine secondary indicators related to influencing environmental risks. Finally, after reviewing the statistical results obtained from the questionnaires and utilizing the TOPSIS technique, seven main indicators including "quality, flexibility, delivery, technology, information and communication systems, cost and experience" along with 24 secondary indicators were obtained relating to the top supplier selection. Also, the delivery factors group was identified as the most important group based on the Friedman test results.

Keywords: Assessment Model; Pharmaceutical Industry; Project Management; Project Risk; Supplier Selection

1 INTRODUCTION

The pharmaceutical industry is defined as a combination of processes, operations and organizations involved in discovery, creation and production of drugs. According to the diversity in the pharmaceutical industry, the present study is mainly focused on the supplier selection and the factors affecting the supplier selection in the drug production projects so as to mitigate the risk involved in this regard. As organizations always try to improve their market share, increase profit and achieve the competitive advantage, they need to consider the project management principles and standard steps toward it. Organizations in the 1960s and 1970s were always trying to increase the competitive power by standardizing and improving processes towards their customers. These efforts were continued in the 1990s by developing the project management methods considering the strategic suppliers and logistic operations [1].

In recent years, by increasing the supplier organization outside the main organization, the outsourcing organizations have been facing the variety of options when selecting the source of supply. Along with this issue, increasing the commercial competition in global markets has caused organizations to pay more attention to optimizing their processes in all competitive aspects including the supplier selection. The decision makers in the field of outsourcing try to select the alternative among the available suppliers which can meet all of the outsourced process needs in the best possible way [2].

1.1 Problem Statement and Research Background

Organizations in the 1960s and 1970s were always trying to increase the competitive power by standardizing and improving their internal processes in order to produce a more qualified and cost-effective product. They mainly believed that a robust engineering and design together with the integrated and coordinated operations are the prerequisites of achieving the market demands and as a result, increasing their market share [3]. Hence, the organizations were mainly focused on increasing their flexibility.

By increasing the customers' expectations in the 1980s, organizations increasingly became interested in improving flexibility in the production lines and developing new products to meet the customers' needs. Along with improving production processes in the 1990s, and well as utilizing the reengineering methods, managers of many industries found that it was no longer enough to improve the internal processes and flexibility and that they needed to cooperate with the best part and material suppliers who produced with the best quality and at the lowest cost. In addition, the distributors needed to have close relationships with the manufacturer's market development policies. Tab. 1 shows some research related to the present study.

Table 1 Research Related to the Present Study

Title	Method	Researcher /year
Identifying and prioritizing the project risk based on PMBOK with fuzzy approach [4]	AHP, TOPSIS	Olfat et al., 2010
Project Risk assessment and management using value engineering approach [5]	Value engineering approach	Alem Tabriz et al., 2014
The project risk deployment model based on EFQM [6]	EFQM	Amiri et al., 2014
Project risk management assessment in mass production projects [7]	MADM	Bani Asadi ez al., 2005
Tunnel building projects risk management [8]	TOPSIS, SAW, LA	Sayadi et al., 2011

Olfat et al. (2010) identified and prioritized the project risk based on PMBOK standard with fuzzy approach in the interchange building project in the Boushehr Province [4]. According to their research results, the accidents are among the most important risks in the interchange building projects in Boushehr Province that can be dramatically mitigated by utilizing the location principles. Alem Tabriz [5] also assessed and managed the project risk by value engineering approach with the aim of utilizing the value engineering techniques in the civil projects risks management so as to improve the project value and mitigate the probable risks. In their research, they calculated the project value index in the case of implementing reactive measures to the projects risks and assessing the costs of these measures after implementing the risk management work plan based on the PMBOK standard and improving the plan in case of decreasing trend of this index through the international standard of value engineering technique (SAVE). According to their findings, utilizing this framework in the Tehran subways project can cause mitigating and dealing project risks to save 49.6 percent in the projects costs after implementing the value engineering technique on the reactive measures facing the most critical project risk and improving the project value index from -3.2 to -1.6. Bani Asad et al. in 2005 have identified and prioritized the civil project risks in Mehr Housing Project using the MADM technique in Iran [7]. Sayadi in 2011 studied the Tunnel building risk management. They evaluated and ranked a relatively complete set of criteria to use in MADM techniques relating the Tunnel building projects in Seymare Dam in the south west of Iran. Also, the experts' views were gathered using the group decision making techniques and the linear allocation methods. Similarity to the ideal solution and the simple weighted set were used to determine the risk ranks. The risks resulted from the economic factors and commitments/ guarantees have the most and the least ranks, respectively [8].

Table 2 Risks involved in production projects management

Risk	Definition
financial	Change in exchange rate
transit time	Change in the transit time including the transportation and clearance
forecast	Errors in needs estimation that resulted in over or under-estimated inventory
Quality	Damaged, unfinished and different products, parts or material in different areas
Safety	The products that endanger safety
Disruption in business	Inability to produce or selling the product to customers
Survival	Factory bankruptcy
Tools and inventory ownership	Disagreement about the inventory ownership, overuse of a vehicle owned by others
culture	Insufficient information about people, culture and language
Opportunism	The supplier's opportunistic behavior with customer
Oil price	Change in oil price

The Project Risk. Sitkin and Pablo (1992) defined the risk as the "range where uncertainty exists about whether it is fulfilled as the potentially successful or disappointing outcomes" [9]. The measures that probably produce the profitable effects mostly include risks. Richi and Brandly also defined the business risks as follows: the level of dealing with the uncertainties that the company should understand and manage when implementing its strategies to effectively achieve business goals [13]. Tab. 2 presents the common risks in managing the production projects including the pharmaceutical projects.

Christopher (2004) classified the risks involved in the production projects in five classes of supply risks, process risks, demand risks, control risks, and environmental risks [9-11]:

Risk of supplying raw materials: one of the most important risks in production that can result from other risks. When we pay for a product or service while the service provider may not meet it with good quality or in time, we face this king of risks which is called the supply risk.

Process risk: when the product is not produced in timely manner or with the needed quantity or quality.

Demand risk: risk resulting from lack or shortage of demand for a special product.

Control risk: resulting from the insufficient quality control.

Environmental risk: the risk of the environmental effects that can result from the physical, social, political, legal, operational and economic environment. The pharmaceutical market is regulated according to the demand and supply nature in many countries. Considering the competitiveness of the pharmaceutical market, governments should balance between economical and healthcare benefits [9]. The pharmaceutical sector plays an important role in the medical and healthcare system. Due to the increasing population and aging, economic growth and epidemic disease (such as cardiovascular disease, and respiratory chronic cancers and disease), the pharmaceutical industry is increasingly growing [12-14].

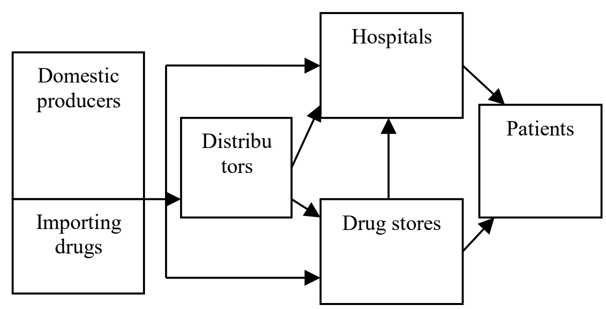

Figure 1 Pharmaceutical industry producers and customers

These are some problems when transition from an planned economy to a powerful company in the pharmaceutical industry:

The ineffective and resultless monitoring [16].

Higher price for a drug means the higher profit for producers [17].

Violation and pricing disproportionately to the preferential prices [18].

Lack of an authorized drug guidance [19, 20].

1.2 Risk Management in Project Management

The term risk, as defined in the PMBOK project management standard 6th version by the PMI institute, has a negative meaning in Persian – it refers to uncertain events in future in project management that can result in an opportunity or threat.

Opportunities or threats can result in some problems if they are ignored while they can be solved with a low cost and turn to valuable opportunities. Hence, the measures that should be taken to deal with them are called risk management.

Risk management is inevitable and it also exists in unorganized projects in an unsystematic and intuitive manner. The point is to achieve the most positive results from the risk management by making it a systematic activity.

According to the PMBOK standard in this regard, the risk management approach should be first determined. Then, risks should be identified and after analysis, the most important one should be selected. Subsequently, the activities to control the important risks and incorporate the obtained results in other plans such as time and cost should be determined. Finally, the results should be evaluated to take necessary actions in case of deviation [21].

Risk management is initiated with managerial planning in the PMBOK standard. Like other managerial plans, risk management plan determines the measures that should be taken in this regard. In addition to methodology, the roles and responsibilities related to risk and the parameters used in future to identify and analyze risk should be determined. After the risk management planning process, risks should be identified in the proper time and with proper tools and consider a hierarchical structure for them which is called the Risk Breakdown Structure (RBS).

After identifying risks based on the PMBOK standard, they should be analyzed from two aspects: quantitative and qualitative. The goal of Qualitative Risk Analysis is to select important risks to plan the proper responses to risk.

After determining the important risks using quantitative and qualitative analyses, they should be planned based on the PMBOK standard during the Risk Management Plan process. After knowing that an event will possibly occur in the future and in that case, has a significant impact on the project, we should think about our response to it. The answer to this question determines the response to the risk.

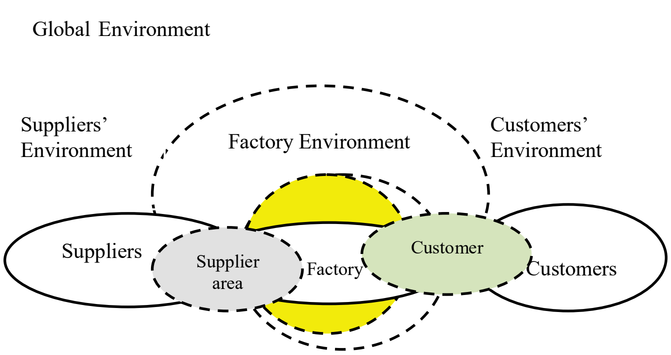

Figure 2 View of risks in the production plants [22]

Tab. 3 shows the risks identified in different stages of production process by different researchers [23].

According to the factors mentioned in different classifications by researchers, the sources of uncertainty have different effects on the organizational decisions.

If the organizational decisions are divided into three different types – operational, tactical and strategic - the interest rate has no effect on strategic decisions, while it has significant effect on operational decisions and a moderate effect on tactical decisions. The other uncertainty sources can also be divided as follows (Tab. 4).

Table 3 The risks identified by different researchers [24]

Identified risks	Researcher
Supplier market risk	Cooke
Quality, delivery, cost, capacity and production tool, technical ability, economical status, management and organization, performance record, guarantees	Dikson
Communication systems, performance controls and workers relationships, information shortage and personal abilities in management and adopting novel procedures	Gooley
Shutting down the transit routes such as docks, conflicts between the management and workers' groups	Machalaba and Kim
Natural and unusual events	Mitroff and Alpalsan
The conflicts between the workers' laws and commercial policies, different cultures and complex managerial structures between the buyer and supplier	Seaman and Stodghill
Terrorism, cyber hackers and natural disasters	Simpson
Natural disasters and technological failures	Stafford et al.
Natural disasters such as flood, earthquake, etc.	Terhune
Price, inventory, technology and quality	Treleven and Schweikhart
Market changes, products, technology, competitors and governmental regulations	Van der Vorst and Heulens
Suppliers communication and integration	Wanger
Capacity constraints, time cycle, disasters, suppliers economical and commercial health, managerial views, increased market price, incomplete information systems and system design changes	Zsidin

Table 4 The effect of uncertainty on the organizational decisions [25]

Uncertainty sources	Operational decisions	Tactical decisions	Strategic decisions
Interest rate	High effect	Moderate effect	--
Supplier delivery time	Low effect	High effect	Low effect
Supplier quality	Moderate effect	Low effect	---
Transportation time	Moderate effect	Moderate effect	Low effect
Random costs	Low effect	High effect	Moderate effect
Political environment	--	--	Moderate effect
Available capacity	Moderate effect	Moderate effect	Low effect
Random demand	Low effect	High effect	Moderate effect
Delay in information access	High effect	Moderate effect	---
Price fluctuations	Low effect	High effect	Low effect

The Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) are considered as two common techniques to study and search for factors and causes contributing to accidental events. Both make logical diagrams to display the faults that distribute through a complex system. FTA investigates all the potential events that resulted in critical events and it is a graphical diagram that shows how system stops [26, 27]. The analysis starts with critical events and then, the essential and sufficiently risky events are identified along with their causes and factors affecting their logical relations using the backward logic. The event tree diagram of the supplier's undesirable performance and its outcomes according to the Brindley and Ritchie paper is displayed in the following figure.

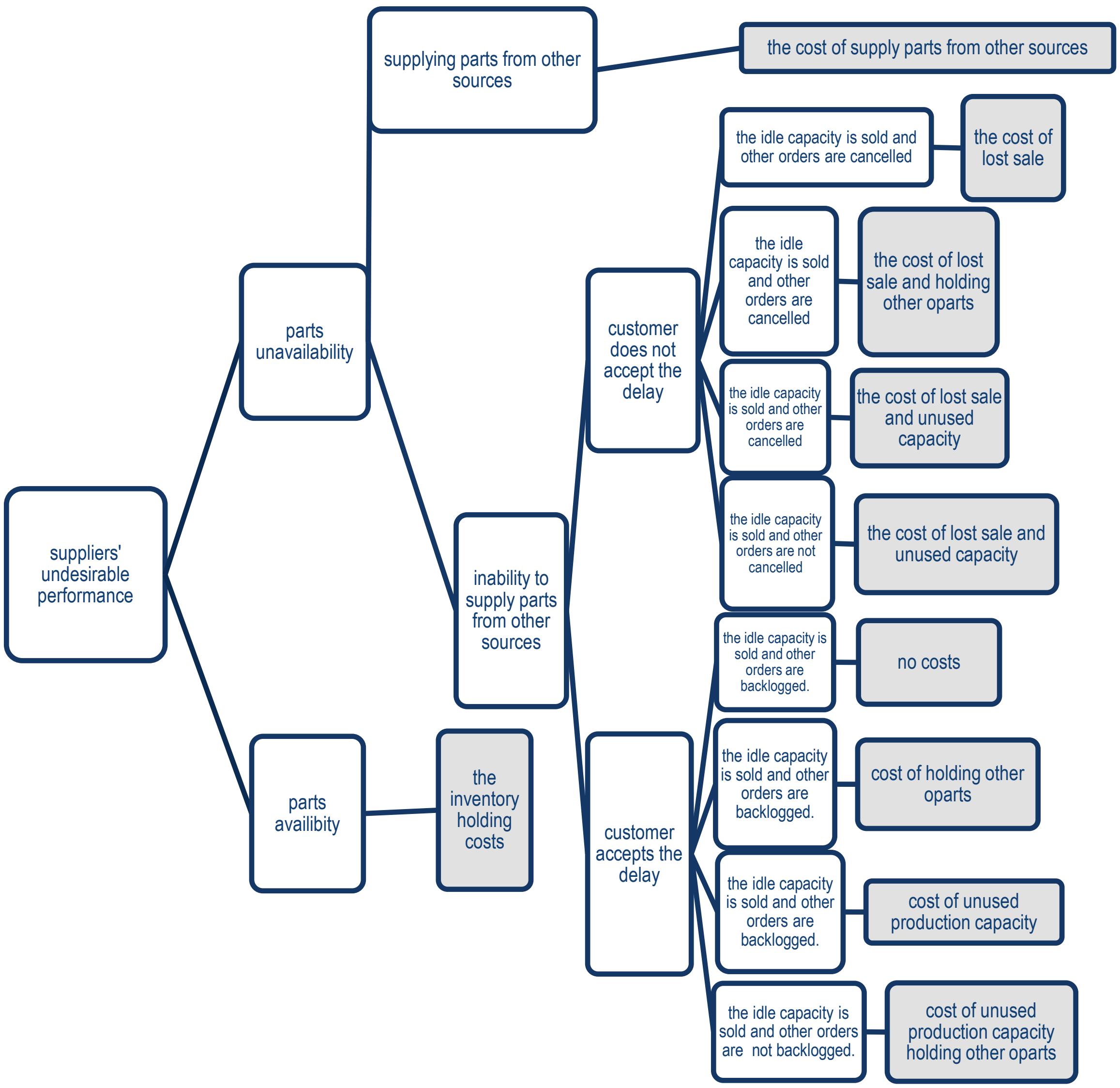

Figure 3 The Fault Tree Diagram of the supplier's undesirable performance and its outcomes

2 RESEARCH METHOD

The present study is an applied and developmental research since it seeks to select a supplier selection model emphasizing risk management in the country's pharmaceutical industry. It is also a descriptive research in tem of the method and a correlational research. In this study, all four areas of "supply, process, demand and environment" should be investigated in terms of the risks in order to identify and assess them and implement the necessary measures to manage them.

Figure 4 Four areas of risk management in the production projects

According to the research literature and subject, risk management is followed in the "pharmaceutical production projects" and along with it, the environmental risks is also considered considering that they affect all three parts of supply chain including "supply risk".

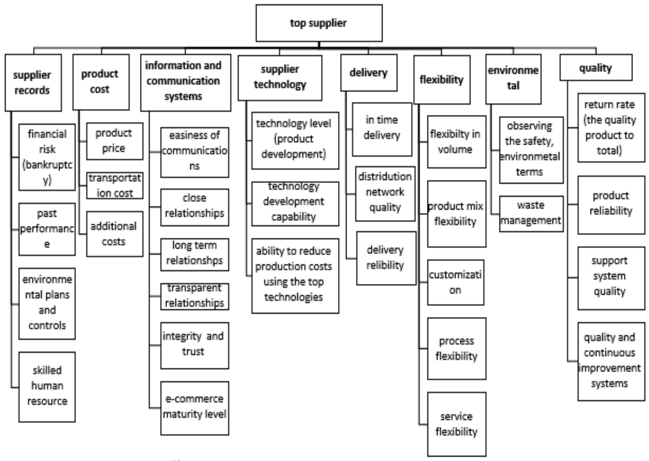

Figure 5 Factors affecting risk management in the pharmaceutical production projects in terms of the supplier [19-22]

The country's pharmaceutical industry is considered in this study as the statistical population. Three large holdings including the Tamin pharmaceutical investment, Alborz investment and Shafadarou Company were also selected as the samples and the data obtained from them were evaluated. The reasons behind selecting these three holdings are:

There are four pharmaceutical producer holdings in the country that hold 75% of drug production share: Tamin pharmaceutical investment including Daroupakhsh and Pars Darou groups, Alborz investment, Shafadarou Company, and HITT. The first three were selected as the samples that hold 65% of the total pharmaceutical market share which is considered as a significant share of pharmaceutical industry. The share of each of these groups is as follows.

Table 5 The market share of the studied holdings

Holding	Production market share	Distribution market share
Tamin pharmaceutical company	22.90	30.65
Alborz	15.86	21.47
Shafadarou	6.55	8.91

Table 6 The research main variables classification

	Variable name	Type	Role
The factors affecting the supplier risk	Quality	rank	independent
	Environmental terms	rank	independent
	Flexibility	rank	independent
	Delivery	rank	independent
	Supplier technology	rank	independent
	Information and communication systems	rank	independent
	Product cost	rank	independent
	Supplier experience	rank	independent
The factors affecting the environmental risk	Economic issues	rank	independent
	Political issues	rank	independent
	Cultural/social issues	rank	independent
	Natural disasters	rank	independent

It should be noted that since the supplier companies do not operate separately and individually, and they are subsidiaries of the producing companies, then a separate market share is not considered for them. The available sampling with the purposeful/judgmental approach is used as the research sampling method. The research main variables are as can be seen in Tab. 6. Since the validity and reliability are two main criteria for testing the measures accuracy and quality, [28], the content validity is used in this study to determine the validity. The professors and experts were asked regarding two options of the question relevance with the subject and its clarity. The reliability was also assessed by the Cronbach's Alpha coefficient as one of the most common tools for this purpose. As the scale with the Cronbach's Alpha coefficient higher than 0.7, it is reliable and the current scale is confirmed with the coefficient higher than 0.8 [29, 30]. After modifications and verifying the questionnaire's validity and reliability, it is used as the data gathering tool.

Table 7 The Cronbach's Alpha coefficient among indicators

No. of questions	Cronbach's Alpha coefficient
39	.806

Table 8 The Cronbach's Alpha coefficient among groups

No of groups	Cronbach's Alpha coefficient
9	.732

The questionnaire was then distributed among mangers in supply, production, planning and logistics sectors. In case of non-availability of the managers in one sector, the questionnaire was filled by the informed expert (which occurred in less than 10% cases). Two questionnaires were removed due to the incomplete information and lack of answers for more than half of the questions. Finally, 62 questionnaires were analyzed. Questions on the respondents' education, experience, tenure and position were provided below. As can be seen, three respondents have a diploma, one has an associate degree, 27 respondents have a license, and 29 respondents have a master degree.

Table 9 Classification based on Education

Education	Frequency	% of Frequency
Diploma	3	4.8
Associate degree	1	1.6
Graduate	27	43.5
Master and above	29	46.8
Not answered	2	3.2
Total	62	100

Table 10 Classification based on Experience

Experience	Frequency	% of Frequency
Lower than 1 year	1	1.6
1-5 years	10	16.1
5-10 years	16	25.8
More than 10 years	31	50
Not answered	4	6.5
Total	62	100

In terms of working experience, one, 10, 16 and 31 respondents have 1 year, 1-5 years, up to 10 years, and more than 10 years of experience, respectively.

In this section, in addition to the descriptive statistics results related to components, the One-Sample T Test was also used with the 95% confidence to examine the components' significance. The table below shows the related information.

Table 11 Descriptive statics related to quality

Questions 1-5		Very low	Low	Mode Rate	High	Very high	SD	*T*	sig	Result
The high return rate of the products received from the supplier	Freq	0	0	4	30	28	0.6	17.9	0	Confirmed
	freq %	0	0	6.5	48.4	45.2				
The good quality of the supplier support system	Freq	0	1	4	34	23	0.6	15.2	0	Confirmed
	freq %	0	1.6	6.5	54.8	37.1				
The quality management and continuous improvement systems in the supplier's factory	Freq	0	0	16	27	19	0.7	10.9	0	Confirmed
	freq %	0	0	25.8	43.5	30.6				
The sense and mentality of the mutual participation and coordination	Freq	0	2	11	31	18	0.7	10.6	0	Confirmed
	freq %	0	3.2	17.7	50	29				
Having the authorized certificates and GMP	Freq	0	0	3	16	42	0.5	22.1	0	Confirmed
	freq %	0	0	4.9	26.2	68.9				

3 DATA ANALYSIS

The One-Sample T Test was also used with the 95% confidence to examine the components' significance. According to the results, as the significance level is *P* value < *a* = 0.05, and *T* has a positive sign, then all the components are confirmed. On the other hand, as *T* is positive, and the Test value is considered at 3, then the resultant components are all more than 3 (average option). The test was also repeated on the groups:

Table 12 The T-test on groups

Group	*T*	Significance	Result
Quality	21.292	0.000	Confirmed
Environmental factors	7.371	0.000	Confirmed
Flexibility	14.956	0.000	Confirmed
Delivery	28.654	0.000	Confirmed
Technology	15.838	0.000	Confirmed
Information and communication systems	16.229	0.000	Confirmed
Cost	21.383	0.000	Confirmed
Record	9.116	0.000	Confirmed

According to Tab. 12, it is found that the significance of all components is confirmed. In other words, all components and groups are proper tools to evaluate variables and the research conceptual model. In addition, according to the One-sample T-test, it is found that the significance of each component/group is more than 3 (the test value) in .05 significance level. The questionnaire components are classified by two methods: Fuzzy TOPSIS and Friedman test using the SPSS software which are described below:

The first method of classification: Fuzzy TOPSIS

The Fuzzy theory is used in the uncertainty conditions which is a mathematical precise and systematic way of modelling the vague priorities [31, 32]. The questionnaire is designed based on the Likert scale and the options are very high, high, moderate, low, and very low with 1 for very low and 5 for very high. The linguistic numbers provided in table 13 are used in order to use triangular fuzzy numbers and based on the studies on different papers.

Table 13 Linguistic Variables [31]

Very low	1	(0 ,0.1 ,0.2)
Low	2	(0.1 ,0.25 ,0.4)
Moderate	3	(0.3 ,0.5 ,0.7)
High	4	(0.6 ,0.75 ,0.9)
Very high	5	(0.8, 0.9, 1)

All questions have the positive meaning and the weights of all the questions are equal and 1. The final result of the components is presented in Tab. 14 according to the priority (from the most significance to the lowest significance).

Table 14 Prioritizing the supplier risks in the production projects based on the Fuzzy TOPSIS

Question	Sub group	C_i
12. in time delivery	delivery	0.140
23. the product lower cost compared to competitors	cost	0.158
14. delivery reliability (no interruption in product delivery)	delivery	0.169
5. the authorized certificates and GMP	quality	0.185
1. Higher return rate of product/raw material from supplier	quality	0.207
25. reducing additional costs compared to competitors	cost	0.215
27. the record of positive performance	record	0.227
21. mutual trust	Information and communication systems	0.237
18. Easiness in relationship	Information and communication systems	0.248
2. Higher return rate of product/raw material from supplier	quality	0.248
24. Lower transition cost compared to competitors	cost	0.262
13. Suppliers' distribution network quality	delivery	0.284
10. Customization	Flexibility	0.306
29. skilled human resource	record	0.329
3. quality and continuous improvement systems	quality	0.339
4. the sense and mentality of mutual participation and collaboration	quality	0.344

Table 14 Prioritizing the supplier risks in the production projects based on the Fuzzy TOPSIS (continuation)

Question	Sub group	C_i
11. service flexibility	Flexibility	0.362
26. no record of bankruptcy	record	0.367
15. the product development technology level in the supplier factory	Technology	0.374
20. long term relationships	Flexibility	0.391
8. volume flexibility	Information and communication systems	0.397
17. ability to reduce production costs using the top technologies	Technology	0.399
19. close relationships	Flexibility	0.414
9. flexibility in received product and raw material diversity	Information and communication systems	0.452
22. E-commerce (IT) maturity level	Information and communication systems	0.490
6. observing environmental terms in the supplier factory	Environmental	0.498
28. having plans to control environmental factors	record	0.515
16. the ability to develop the production technology in near future in supplier factory	Technology	0.533
7. waste management in the supplier factory	Environmental	0.567
30. number of agreement of supplier with the multi-national companies	record	0.597

Table 15 Prioritizing the environmental risks based on the Fuzzy TOPSIS

Question	Sub-group	C_i
31. change in exchange rate	environmental risks	0.156
36. sanctions	environmental risks	0.207
33. change in customs policies and tariffs	environmental risks	0.254
32. change in interest rate	environmental risks	0.326
35. country’s political transformation	environmental risks	0.329
37. war and terrorism	environmental risks	0.385
34. change in paid tax	environmental risks	0.402
38. natural disasters	environmental risks	0.493
39. change in consumer’s taste	environmental risks	0.680

The second method of classification: Friedman Test

The second method of classification is Friedman test [33] in which, the significance level is also lower than 0.05.

Table 16 Friedman Test for components

No. of questionnaires	61
Chi-square	436.569
DoF	38
sig	0.000

Since the significance level is also lower than 0.05 in this test (0.000), the test is confirmed for the questionnaire components. The components 12 and 23 and the components 30 and 7 are the components with highest and lowest significance in this test, respectively (similar to the Fuzzy TOPSIS technique).

There is a partial difference between two methods; however, the components have relatively the same significance in both methods. Regarding the environmental risks, the question 31 is determined as the most important risk by respondents in both methods and the question 39 has the lowest importance among the environmental components. This test was also used in order to study the group importance.

Table 17 Prioritizing the supplier risks in the production projects based on Friedman Test

Question	Mean Rank	Priority
1	22.89	8
2	21.65	11
3	18.13	20
4	18.32	19
5	26.73	3
6	15.67	25
7	13.73	29
8	16.88	23
9	17.47	21
10	20.59	13
11	17.42	22
12	27.75	1
13	21.22	12
14	26.22	4
15	20.09	15
16	14.36	27
17	19.77	16
18	22.30	10
19	15.80	24
20	18.58	18
21	23.52	7
22	14.93	26
23	27.62	2
24	22.80	9
25	24.84	5
26	19.54	17
27	23.80	6
28	14.21	28
29	20.26	14
30	12.51	30

Table 18 Prioritizing the environmental risks based on Friedman Test

Question	Mean Rank	Priority
1	26.66	1
2	20.80	2
3	23.72	3
4	18.99	4
5	20.12	5
6	24.07	6
7	19.22	7
8	15.50	8
9	11.32	9

Table 19 Friedman test for groups

No. of questionnaires	61
Chi-square	111.913
DoF	8
Sig	0.000

As the significance level is lower than .05 in this test (0.000), this test is also confirmed for groups.

Table 20 Prioritizing based on Friedman test

Group	Mean Rank	Priority
Quality	5.50	3
Environmental factors	3.30	7
Flexibility	4.25	6
Delivery	7.03	1
Technology	4.39	5
Information and communication systems	4.65	4
Cost	6.93	2

As can be seen, the most important group for the supplier selection is the delivery factors group (including the in time delivery, distribution network quality, and delivery reliability) and the least important group is the environmental issues in the supplier factory.

4 CONCLUSION

The present study aimed to provide a supplier selection model emphasizing the project risk management in drug production in the country's pharmaceutical industry utilizing the Fuzzy TOPSIS technique as well as the Friedman Test to prioritize groups. According to the priorities obtained in the Fuzzy TOPSIS technique and the Friedman Test, the data in 20% top of the means were eliminated (due to elimination of the least important data).

Table 21 The means based on group priority in supplier selection in pharmaceutical industry

Group	Component	Mean C_i %
delivery	12. in time delivery	40.96
	13. suppliers' distribution network quality	83.09
	14. delivery reliability (no interruption in product delivery)	49.44
cost	23. the product lower cost compared to competitors	46.23
	24. lower transition cost compared to competitors	76.65
	25. reducing additional costs compared to competitors	62.90
quality	1. Higher return rate of product/raw material from supplier	60.56
	2. proper quality of the supplier support system	72.56
	3. quality and continuous improvement systems	99.18
	4. the sense and mentality of mutual participation and collaboration	100.64
	5. the authorized certificates and GMP	54.13
Information and communication systems	18. easiness in relationships	72.56
	19. close relationships	132.24
	20. long term relationships	116.15
	21. mutual trust	69.34
	22. e-commerce maturity level	143.36
Flexibility	10. Customization	89.53
	11. service flexibility	105.91
	8. volume flexibility	114.39
	9. flexibility in received product and raw material diversity	121.12
record	26. no record of bankruptcy	107.37
	27. the record of positive performance	66.41
	28. having plans to control environmental factors	150.67
	29. skilled human resource	96.26
	30. number of agreement of supplier with the multi-national companies	174.66
technology	15. the product development technology level in the supplier factory	109.42
	16. the ability to develop the production technology in near future in supplier	155.94
	17. ability to reduce production costs using the top technologies	116.73
Environmental	6. observing environmental terms in the supplier factory	145.70
	7. waste management in the supplier factory	165.89

As can be seen in the table of C_i means, the e-commerce maturity level, having plans to control the environmental factors, the agreements of the intended supplier with the multi-national company, the ability to develop the technology for supplier factory are the importance factors in suppler selection in pharmaceutical industry. It is better to eliminate them from the top supplier selection indicators in the country's pharmaceutical industry. Based on the table of the C_i means in the environmental risks, "change in the consumers' tastes" has no effect on the country's pharmaceutical industry or in other words, it has a low value in managing the environmental risks in the country's pharmaceutical industry in terms of the experts. The following points should be considered in order to reduce the supplier risk in the drug production projects.

The change in the consumer's taste is not an evaluable factor in the pharmaceutical industry.

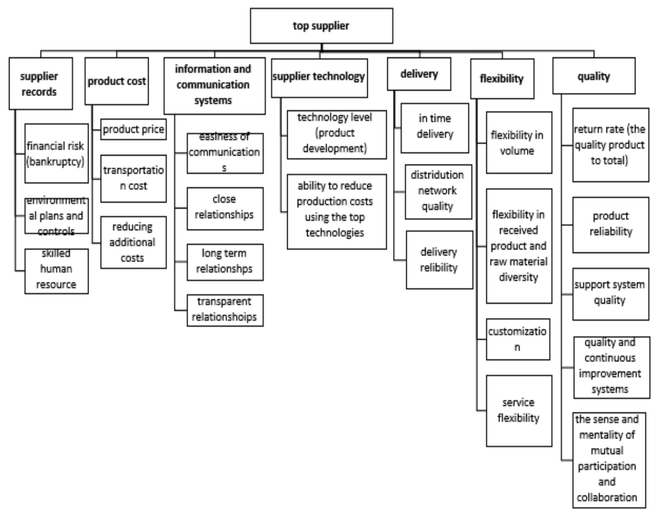

Figure 6 The final model of top supplier selection in the pharmaceutical industry

The priority in the supplier selection is related to ones who meet the delivery and cost indicators to the best possible way.

For this purpose, they should have in-time delivery, a distribution network with proper quality, and not interrupt the supply of the raw material/product suddenly.

On the other hand, their prime price should be lower than the competitors' of the same quality. Having the authorized certificates, including the Ministry of Health certificates and GMP etc., is in priority of decisions; however, the Ministry of Health permission is needed with regard to procuring the pharmaceutical raw material.

Flexibility in volume and services as well as the product diversity do not matter in the pharmaceutical industry because the pharmaceutical raw materials follow special standards and terms that changing them is not desirable for the buyer.

In line with the supplier's selection desirable terms, the environmental risks should not be ignored. Accordingly, the supplier with a plan for economical-political risks is in priority.

The change in the interest rate, sanctions, change in the customs tariff, etc., can result in the supplier failure and consequently, product supply interruption if these measures are unplanned.

The following suggestions can be considered in this regard for the future research:

The present research perspective to define the risk events is a project risk management and a customer-oriented view and it also considers the events resulting in the customer dissatisfaction – the producer's view in this research – to the supplier's activities as the risk events.

However, it should not be ignored that the customers' expectations and views are not the only important issue but the other groups' views including shareholders, employees, suppliers, and even society is important.

Hence, the more holistic view can consider these views in defining the risk events and build a model to incorporate these views.

For example, the risk drivers should also be defined and measured in this regard considering the shareholders' and company owners' views.

The statistical population in this study consisted of the pharmaceutical industry supply chain including Tamin pharmaceutical investment, Alborz investment, and Shafadarou Company.

The use of a broader statistical population like the whole pharmaceutical industry or incorporating other main holdings can provide a bigger sample and hence, more generalizable results.

The risks identified in this research can be ranked utilizing the project management methods based on the PMBOK standard.

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Optimization of Managerial, Organizational and Technological Solutions of Grain Storages Construction and Reconstruction

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Abstract: The work is devoted to the important problem of optimization of managerial, organizational and technological solutions of construction and reconstruction of separate grain storages and the management of specialized building enterprise as a whole. Models of the company for the grain storages construction and renovation were designed, analyzed and described: multidimensional organizational structure, computer model of the enterprise. The results of a two-stage construction products cost optimization were presented. The recommendations for the adoption of optimal organizational and technological solutions were developed. The method for justification of financial income level for the grain storages construction and reconstruction using project management principles and provisions of the existing regulations was proposed.

Keywords: construction and reconstruction of the grain storages; business management techniques; multidimensional organizational structure; optimization; management; organizational and technological solutions

1 INTRODUCTION

The work is devoted to the important problem of optimizing the managerial, organizational and technological solutions of construction and reconstruction of separate grain storages and the management of specialized building enterprise in general.

Profitability is one of the key performance indicators in the management of individual objects in the grain storages construction or reconstruction, as well as managing the company's operational activity for the construction of such facilities. Modeling of resource assignments for construction and installation work performed during the grain storages construction or reconstruction, allows showing the full cost of production. Analysis of all construction projects, with a total budget conditionally equal to the average budget of the specialized enterprise, simulates the full structure of production costs and the profitability of such a construction organization.

It is obvious that the links are possible between different organizational and technological solutions for enterprise management in general and the construction of individual construction projects. This relationship may be modeled by multidimensional managerial structure. Its research will improve the quality of managerial decisions. Variation of organizational and technological solutions will change the structure and addends of the total production costs, the organizational structure of the enterprise. Construction of computer models of the totality of construction projects will allow tracking changes of the most important indicators of financial performance under the influence of different factors of organizational and technological nature.

The high relevance of the article is determined by large scale, special features of management of the grain storages construction and reconstruction, the absence of specific recommendations in the area under consideration and the availability of organizational and technological reserves of optimization.

2 AIM AND TASKS OF THE ARTICLE

This article aims to optimize the managerial, organizational and technological solutions for grain storages construction and renovation by organizational and economical mathematical modeling of operations of the specialized enterprises and the development of rational tools of their management.

Article tasks are the following:

1. Analyze information sources on the subject of research: the conditions of the grain storages construction and renovation, methods of organizational and numerical modeling.
2. Develop methodology for numerical simulation of the operating activity of the grain storages construction and renovation enterprise.
3. Develop models of the enterprise operating activity under consideration: a multi-dimensional organizational model, the computer model.
4. Get the numerical regularities of performance change in the enterprise operating activity and find the optimal organizational and technological solutions.
5. Suggest rational enterprise managerial tools for the construction and renovation of grain storages.

3 ANALYSIS OF INFORMATION SOURCES

Data on the segmentation of the grain storages construction market in the world [1-5] show that a significant proportion of the work is to upgrade existing storage facilities. Typically, this modernization involves the commissioning of new silos, the upgrading of technological equipment, productivity enhancement of transport lines and individual technological units of grain storage, associated with this dismantling work and the construction of small additional structures. As a rule, grain storage modernization is rarely of large scale. Grain storages reconstruction projects may have a budget up to 1 million UAH and labor input of construction and installation works up to 3 thousand hours

[5, 6]. Nevertheless, there are still tendencies to build new wide-scale grain storages and carry out large-scale renovation of existing ones. It can be concluded that the largest object for a typical grain storages construction and renovation enterprise has a budget of about 25-30 million UAH and the total labor intensity of construction and installation works for about 40 thousand hours [5, 6].

Analysis of types of enterprises organizational structures showed that the most common types are linear, linear-staff, project, matrix, multidimensional. The difference of these structures lies in different priorities of vertical and horizontal managerial relationships between their elements. Matrix and most multidimensional structures have the highest priority of horizontal relations among the considered structures. The development of such relations can be effective in the variable environment in which the company sells its activity [7].

It is advisable to use a simulation to improve construction activity. The most effective simulation of the operating activity of the enterprises is to build analytical, deterministic, optimizing, imitative, static, correlative-regressive, network models [8, 9].

The fundamental works on the organization of construction process proved that there was a correlation between the management processes of the organization and construction projects [10, 11]. It is proposed [12], that the operations of construction enterprises may be modeled using multidimensional organizational structures.

Analysis of works, devoted to the optimization of organizational and technological solutions for construction and reconstruction [13, 14], allows the conclusion that the application of experimental statistical modeling is an effective way of solving similar problems and can be used in modeling and optimizing the operating activity of enterprises for construction and renovation of dispersed different scale buildings.

The application of experimental statistical modeling for the methods of optimization are discussed in [15-17]. Also, the methods of optimization with the application of experimental statistical modeling are presented in [18-20]. It is advisable [21, 22] to use specialized programs for project management to create a model of the operating activity of the construction organization.

In the course of operational activity, important issues arise in the management of enterprise costs accounting. According to numerous works [23-24], it is advisable to divide cost by the accounting standard into direct costs and general production ones.

Regulatory methods for calculating costs and revenues are based on the use of a database of resource rates per unit of physical measurement of work, regulatory indicators of general production, administrative costs and profit on the consolidated labor input of construction [25, 26]. It is also allowed to use actual data for the calculation of general production and administrative costs indicators for construction enterprises [27, 28]. The usage of the internal database of resource rates per work unit is not prohibited for the construction company [26]. When managing projects [29], the special attention is recommended to pay to the formation of a full and detailed content and cost of the project, as well as to integrate them with the goals of the project-oriented enterprise as a whole. That means to consider the cost of the project only in the context of the organization that implements it.

4 OVERALL METHODOLOGY OF STUDY

Fig. 1 shows the block diagram of the experimental studies.

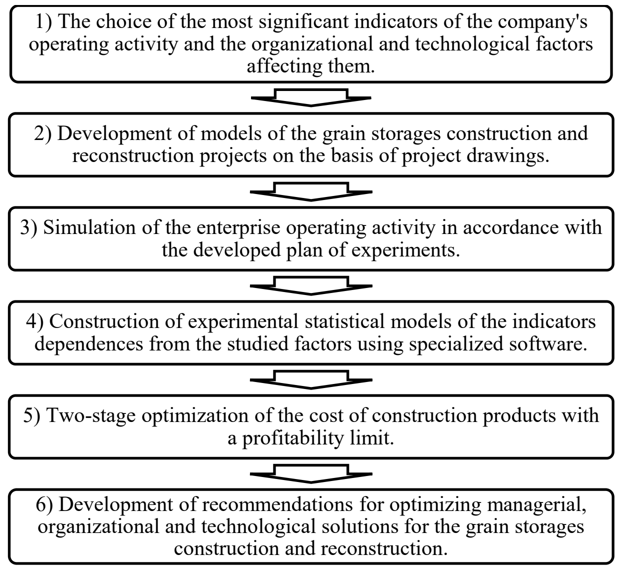

Figure 1 Block diagram of the experimental studies to optimize the organizational and technical solutions grain storages construction and reconstruction enterprise

The polynomial experimental statistical (ES) model was selected in this study in order to solve optimization problems. Eq. (1) presents it in a common form:

$$\begin{aligned} Y_n &= b_0 + b_1 X_1 + b_{11} X_{12} + b_{12} X_1 X_2 + b_{13} X_1 X_3 + \\ &+ B_{14} X_1 X_4 + b_2 X_2 + b_{22} X_{22} + b_{23} X_2 X_3 + B_{24} X_2 X_4 + \\ &+ b_3 X_3 + b_{22} X_{22} + b_{33} X_{32} + b_{34} X_3 X_4 + B_4 X_4 + b_{44} X_{42} \end{aligned} \quad (1)$$

The transition to the coded variables was configured by the typical equation:

$$x_i = \frac{X_i \frac{X_{i\,\max} + X_{i\,\min}}{2}}{\frac{X_{i\,\max} - X_{i\,\min}}{2}} \quad (2)$$

where: x_i – predetermined level of factor in a normalized form; X_i – predetermined factor level in natural form; $X_{i\,\max}$ – the maximum level of the factor in its natural form; $X_{i\,\min}$ – the minimum level of factor in its natural form.

Tab. 1 presents the plan used in numerical experiment.

The calculation of the regression coefficients was carried out according to standard equations using interactive COMPEX system. The regression coefficients are statistical estimates of the true coefficients of the addendum of the polynomial model, therefore, require verification of the difference between estimates of coefficients of ES-models and zero. This test was carried out at bilaterally specified risk equal to 10% ($\alpha = 0.1$, or ± 5%), in accordance with Gaussian distribution law. After sieving coefficients, which were recognized indistinguishable from zero, ES-model with all significant coefficients was checked for adequacy by Fisher test. If the criterion was less critical for a given risk in view of the obtained degrees of freedom, i.e. $F_a < F_{kr}$ (α, f_{na}, f_e), it was adequate.

Table 1 Plan of numerical experiment in coded variables

#	Normalized factor values				#	Normalized factor values			
	X_1	X_2	X_3	X_4		X_1	X_2	X_3	X_4
1	2	3	4	5	1	2	3	4	5
1	1	1	1	1	13	-1	-1	1	1
2	1	1	1	-1	14	-1	-1	1	-1
3	1	1	-1	1	15	-1	-1	-1	1
4	1	1	-1	-1	16	-1	-1	-1	-1
5	1	-1	1	1	17	1	0	0	0
6	1	-1	1	-1	18	-1	0	0	0
7	1	-1	-1	1	19	0	1	0	0
8	1	-1	-1	-1	20	0	-1	0	0
9	-1	1	1	1	21	0	0	1	0
10	-1	1	1	-1	22	0	0	0	1
11	-1	1	-1	1	23	0	0	-1	0
12	-1	1	-1	-1	24	0	0	0	-1
					25	0	0	0	0

The computer model of the operating activity of the enterprise was considered as the system under investigation. This model was variable under the action of studied factors according to the experimental design.

Fig. 2 presents the method of modeling the total production cost and the cost of construction products for grain storages construction and renovation. Fig. 3 shows the method of modeling the profitability of the enterprise in question in accordance with the recommendations of normative documents of Ukraine [28].

5 MODELING OF OPERATING ACTIVITY OF GRAIN STORAGES CONSTRUCTION AND RECONSTRUCTION ENTERPRISE

Tab. 2 presents description of the elements of the developed models.

Construction products can be described as a set of indicators, by which they are shown. It can be written that the construction products are characterized by the following performance indicators (Eq. (3)):

$$ICP \subseteq \left\{ \{Y_{\text{tech.}}\}, \{Y_{\text{econ.}}\}, \{Y_{\text{env.}}\}, \{Y_{\text{soc.}}\} \right\} \tag{3}$$

Table 2 The determinants of the organizational structure of the enterprise business processes of the grain storages construction and renovation enterprise

Designation	Full title
ICP	– indicators of construction products
DCC	– departments of construction company
R	– resources for the building production
MCE	– management of construction enterprise
MCP	– management of construction project
S	– suppliers
WBS	– work breakdown structure

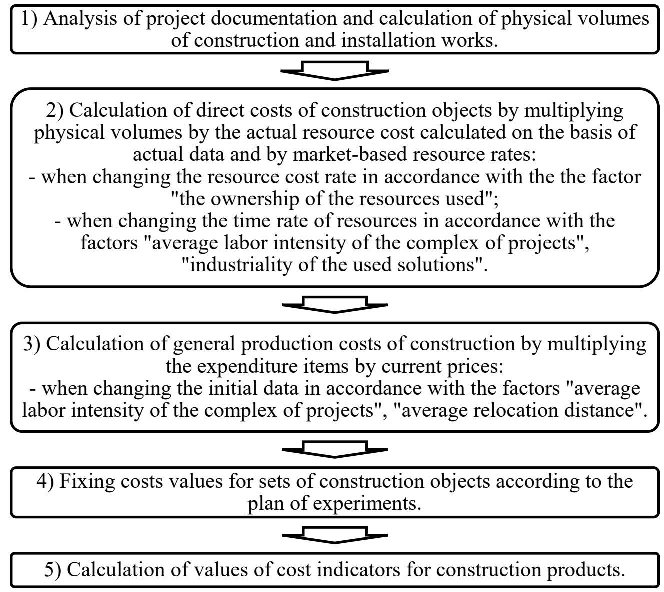

Figure 2 Method of modeling the full production costs and the cost of construction products

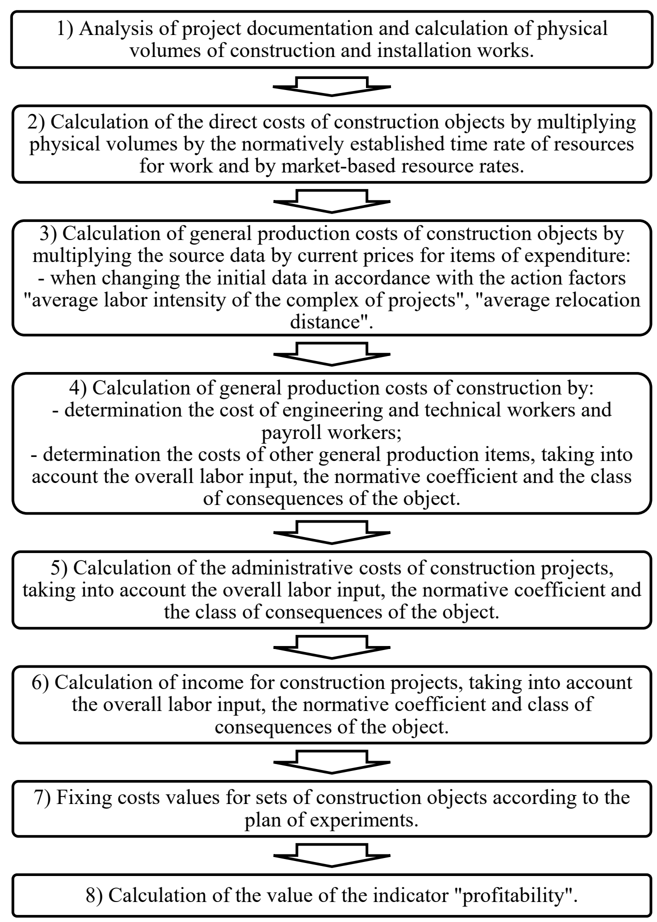

Figure 3 Method of modeling profitability of the enterprise in accordance with the recommendations of normative documents

where: $\{Y_{\text{tech.}}\}$ – indicators of technical efficiency; $\{Y_{\text{econ.}}\}$ – indicators of economic efficiency; $\{Y_{\text{env.}}\}$ – indicators of environmental efficiency; $\{Y_{\text{soc.}}\}$ – indicators of social efficiency.

In this study, the following indicators were suggested:

- Y_1 – profitability – the percentage ratio between the value of the total production costs, calculated on the basis of actual operating data of the enterprise, and the value of income, calculated in accordance with the regulatory procedure. Such revenues include compensation for direct costs of general production, administrative costs and profit.
- $Y_{2\text{-}6}$ – Cost of construction products – direct costs of the construction products. The cost prices were calculated for the following main units: the concrete structures arrangement (Y_2 – 1 m^3), installation of bearing steel structures (Y_3 – 1 t.), silo (Y_4 – 1 m^3), the transport equipment installation (noria (Y_5), conveyor (Y_6) – 1 m).

Thus, the construction products (*ICP* indicators) included for the present study: (Eq. (4))

$$ICP \subseteq \{Y_1, Y_2, Y_3, Y_4, Y_5, Y_6\} \tag{4}$$

Tab. 3 shows the variation matrix of factors taken in this study as the input parameters of the system under study.

Table 3 Matrix variation factors

Factor name	Factor levels		
	−1	0	+1
X_1 - average labor input of the projects totality	2.2 thousands hours	19.6 thousands hours	37 thousands hours
X_2 - average relocation distance	100 km	550 km	1000 km
X_3 - membership of resources used	0%	50%	100%
X_4 - industriality of applied solutions	0%	50%	100%

Considered indicators and factors, as well as internal determinants, can be presented as a multi-dimensional organizational structure of the enterprise management for the grain storages construction and renovation (Fig. 4).

Multidimensional structure shown in Fig. 4 allows to group construction projects performed by the organization, depending on their scale (X_1) and territorial dispersion (X_2). This makes it possible to analyze the technological organizational relationship between such construction projects. Various organizational and technological solutions (X_3, X_4) are possible while performing construction works on individual projects. The model shows that there is a relationship between the organizational structure (DCC) and its managerial methods (MCE), as well as between the structure (WBS) and control methods (MCP) of individual projects. It can be noted that the resources (R: labor, material, technical, intellectual, financial, and technology), used in the creation of construction products, can be put in order through the project work breakdown structure (WBS). As seen from the figure, the developed multidimensional managerial structure is a tool for transforming external resources provided by suppliers into construction products.

Developed multidimensional organizational structure (Fig. 4) allowed solving one of the problems of the rationalization of managerial, organizational and technological solutions of grain storages construction and reconstruction– improving organizational structures of considered enterprises. Namely, the rationalization was possible due to a new approach to:

- formalizing the management interactions between elements of the considered companies operating activity in vertical and horizontal directions;
- organization of operating activity of enterprises under consideration and construction projects logistics at various levels of variable factors.

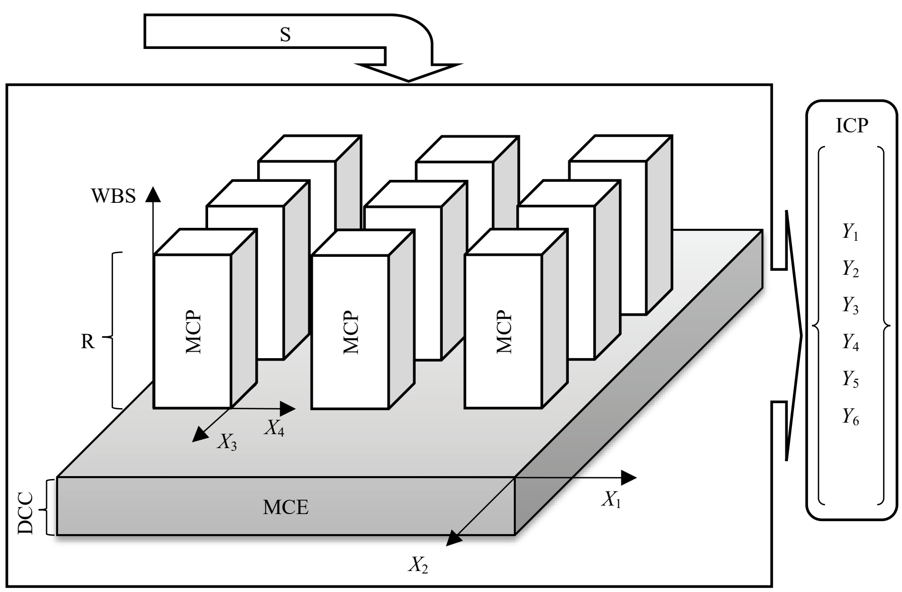

Figure 4 The multidimensional organizational structure of the grain storages construction and reconstruction enterprise

It is necessary for the success of the numerical experiment: to build a trustworthy computer model of the system under study; to choose the input and output parameters – factors and indicators. Data of the construction projects was used to create a computer model of the optimization of the operating activity of the grain storages construction and reconstruction enterprise. Its structure is presented in the graphical analytical form in Fig. 5.

The presented computer model (Fig. 5) was variable, as the levels of its input parameters (factors) vary in the numerical experiment. The variability of computer model was possible under the influence of each factor by:

- X_1 – the average labor input of the projects totality. The compliance of a considering set of projects with the desired value of the variation characteristic should be ensured – the arithmetic mean of labor input of construction and installation works on the projects of this totality.
- X_2 – the average relocation distance. The necessary value of the variation characteristic (the arithmetic mean of distances relocation of resources between any two objects of the chosen totality) was taken as an input when calculating the cost of relocation of industrial and household premises, vehicles, machinery and construction equipment as a part of general production costs.
- X_3 – membership of resources used. The difference of using the subcontract resources in comparison with the own resources was characterized as follows: unit prices for the resource (labor, machinery or equipment) are higher by 18%, which is justified by the market situation in Ukraine. However, the cost of relocation of industrial and household premises, vehicles, machinery and construction equipment will be lower, since the involvement of subcontractors is desirable when their material and technical supply base is closer to the construction site. In this study, it is accepted that the use of subcontractor resources relocation costs is reduced by 2 times. This change is introduced together with the varying of the X_2 factor.
- X_4 – industriality of applied solutions. This factor had a complex effect on the methods of work production of the grain storages construction and renovation. The use of industrial methods allowed achieving this: pre-prepared construction equipment, materials, products and structures; the streamflow organization of production operations; the mechanization rate of work. Simulation of this factor is done by resource assignments adjustment of corresponding works.

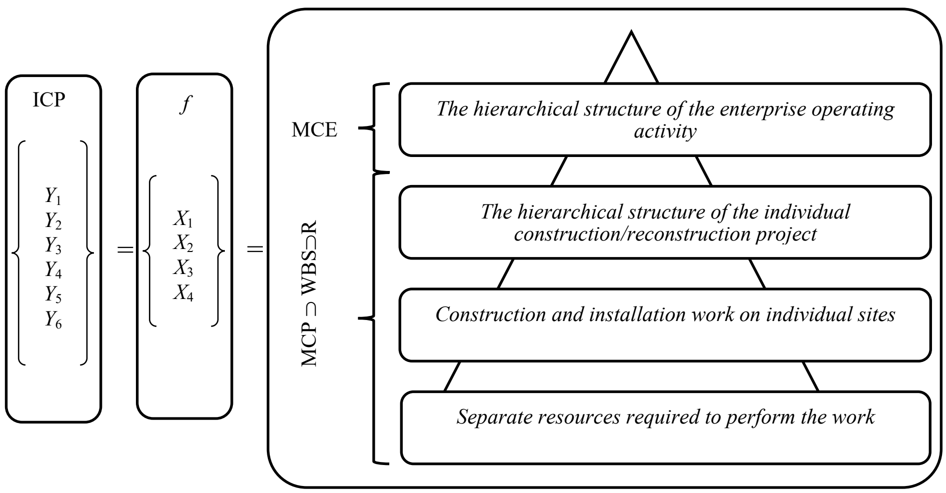

Figure 5 Graphical analytical form of a computer model of the operating activity of the grain storages construction and renovation enterprise

6 OPTIMIZATION OF ORGANIZATIONAL AND TECHNOLOGICAL SOLUTIONS OF GRAIN STORAGES CONSTRUCTION AND RECONSTRUCTION

Tab. 4 presents the results of the experimental statistical modeling.

The indicator changes of profitability are presented in Eq. (5). Factors, recognized by Student's test as indistinguishable from zero, are not shown here or below.

$$\begin{aligned} Y_1 &= 11.5549 - 0.2591X_1 - 0.0178X_2 - 0.0761X_3 - \\ &-0.0467X_4 + 0.0024X_1X_2 + 0.0004(X_1X_2 + X_1X_4) \end{aligned} \tag{5}$$

Analysis of addendum characters of the Eq. (5) showed that the influence of the factor X_1 ("average labor input of projects totality") increments the profitability (Y_1) both in in its individual influence and when combined with other influencing factors. However, the individual influence of factors X_2 ("average relocation distance") and X_3 ("membership of resources used") reduces the indicator value.

The most convenient graphical representation of the analytical dependence of the four factors is the chart "squares on the square". It reflects the change of the indicator from two factors within nine "small" squares, which are located on the "big" square, showing nine combinations of the values of the other two factors.

Fig. 6 shows the regularity of profitability change (Y_1) from the membership of resources used (X_3) and the industriality of applied solutions (X_4) for nine combinations of values of the average labor input of the projects totality (X_1) and the average relocation distance (X_2).

Hereafter, the indicator extrema within two-factor diagrams are marked by bold; the extrema within the entire diagrams – underlined; factor levels values – italics.

The analysis of Fig. 6 allowed noting the following. The character of factor influence "industriality of applied solutions" (X_4) does not change depending on the level of factor "average relocation distance" (X_2), but is different at different levels of the factor "average labor input of the projects totality" (X_1).

Magnification of factor X_4 reduces the value of the indicator when X_1 = 2.2 thous. hours; factor X_4 does not affect indicator when X_1 = 19.6 thous. hours; factor X_4 increases the value of the indicator when X_1 = 37 thous. hours. Character of influence of factor "membership of resources" (X_3) changes depending on the area of factors' space: the parameter decreases with increasing of levels of this factor.

Thus, it was concluded that the application of subcontracting forces on the grain storages construction and reconstruction facilities reduces the profitability of 5-7% at all levels of strategic factors of organizational technological nature. Application of industrial construction methods can only be justified on large (X_1 = 37 thous. hours) grain storages construction and reconstruction facilities, increasing the profitability from 3.24 to 5.1%. Such methods reduce profitability of 2.31-4.4% on small objects (X_1 = 2.2 thous. hours).

Table 4 Results of the experimental statistical modeling

#	Indicators					
	Profitability, Y_1	Cost of reinforced concrete structures unit, Y_2 (thous. UAN/m^3)	Cost of load-bearing metal structures unit, Y_3 (thous. UAN/ton)	Cost of grain silo storage installation, Y_4, (UAN/m^3 storage)	Cost of noria section installation, Y_5 (thous. UAN/m)	Cost of conveyor section installation, Y_6 (UAN/m)
1	-2.24%	3,276.17	4,653.77	41.50	1,196.46	794.88
2	-7.69%	3,766.31	5,170.86	49.66	1,329.40	883.20
3	2.92%	3,162.74	4,046.76	36.13	1,040.40	709.00
4	-1.20%	3,627.29	4,496.40	43.24	1,156,00	787.77
5	0.11%	3,276.17	4,653.77	41.50	1,196.46	794.88
6	-4,41%	3,766.31	5,170.86	49.66	1,329.40	883.20
7	6.23%	3,162.74	4,046.76	36.13	1,040.40	709.00
8	2.08%	3,627.29	4,496.40	43.24	1,156.00	787.77
9	-17.65%	3,888.06	4,653.77	72.88	1,218.85	843.68
10	-13.65%	3,722.22	5,170.86	87.43	1,314.07	937.42
11	-9.83%	3,736.82	4,046.76	63.49	1,059.87	752.42
12	-6.32%	3,586.13	4,496.40	76.16	1,142.67	836.02
13	-1.81%	3,888.06	4,653.77	72.88	1,218.85	843.68
14	2.12%	3,722.22	5,170.86	87.43	1,314.07	937.42
15	6,00%	3,736.82	4,046.76	63.49	1,059.87	752.42
16	9.46%	3,586.13	4,496.40	76.16	1,142.67	836.02
17	-0.62%	3,452.90	4,591.95	42.55	1,180.56	793.71
18	-6.18%	3,733.31	4,591.95	74.84	1,183.86	842.39
19	-3.74%	3,448.75	4,591.95	43.04	1,188,16	818.38
20	0.36%	3,448.75	4,591.95	43.04	1,188.16	818.38
21	-4.87%	3,511.51	4,912.32	46.01	1,271.05	865.33
22	-2.82%	3,286.01	4,653.77	41.97	1,205.04	819.87
23	1.49%	3,385.98	4,271.58	40.06	1,105.26	771.43
24	-3.61%	3,678.66	4,833.63	46.98	1,249.87	861.37
25	-1.69%	3,448.75	4,591.95	43.04	1,188.16	818.38

In general, there was negative profitability in many areas of the investigated factor space when considering the income, calculated in accordance with the recommendations of existing regulations and the expenses calculated according to the analysis of the actual costs of the grain storages construction and reconstruction enterprise. This proved that the regulatory methods for calculating construction companies' income are imperfect.

Considered data showed that the method of calculating the general production and administrative costs, which is recommended in current regulations, is not effective enough to calculate the construction companies who build on sites with a small distance relocation (profitability is $Y_1 = 1.78 \div 9.3\%$). In addition, it is ineffective for enterprises which build the objects with an average relocation distance more than X_2 = 625 km (profitability decreases to Y_1 = -17.58%). Also, the operating activity of companies specializing in the construction on small-scale sites (X_1 = 2.2 thous. hours) becomes unprofitable at average relocation distance equal X_2 = 495 km.

All of the above proves that the most effective approach is to use project-based methods to justify the income value, especially for the general production costs, administrative costs. Namely, to conduct detailed calculation of all items of expenditure according to § 4.3.8, 5.3.6 of the [9]. There cannot be is invited to apply the additional calculation of general production, administrative costs to the calculation of direct costs. 0.6-4.5% of profitability can be reached by taking into account the additional calculation of general production, administrative costs for enterprises operating activity. Such low profitability values require the use of a project approach to the justification of the estimated profit (§ 6.1.2 instructions [9]).

The profit value can be justified in the construction contract based on simulation and considering:

- the degree of uniqueness of erected structure;

- the need to form a temporary project management team for work in special conditions;
- one-night performance of the construction project, respectively, the unique nature of the distribution of profit over time.

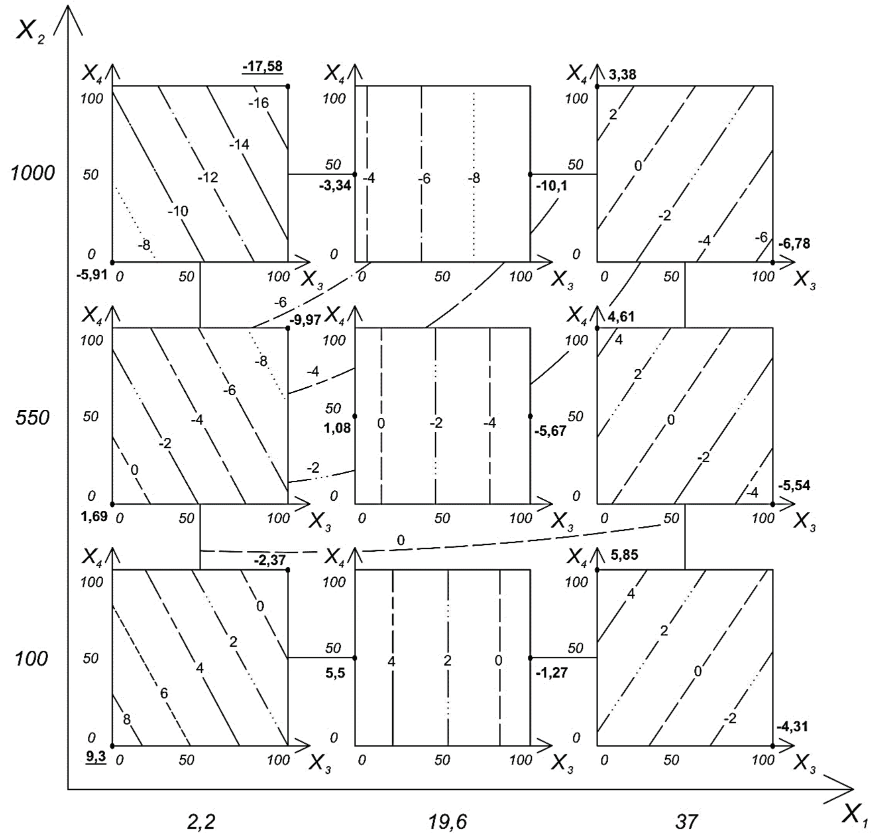

Figure 6 Change of profitability (Y_1, %) depending on membership of resources used (X_3, %) and industriality of applied solutions (X_4, %) at various strategic solutions of the enterprise management

The indicator changes of cost of reinforced concrete structures unit (Y_2) are represented in analytical form in Eq. (6):

$$Y_2 = 3634.4 - 16.475X_1 + 0.453X_1^2 - 0.183X_1X_4 + \\ +1.339X_3 - 1.801X_4 \quad (6)$$

The analysis of Eq. (6) showed that increasing of factors "average labor input of the projects totality" (X_1) and "industriality of applied solutions" (X_4) reduces the value of indicator Y_2, while the factor "membership of resources used" (X_3) increases. This is indicated by addendum characters of the first degree corresponding variables. Large scale construction sites allow to use industrial methods of work, as well as to increase productivity through the use of in-line production of work. The savings due to the involvement of closely spaced resources without the need to spend money to reline are not taken into account, since the cost of construction products includes only the direct costs.

The optimization of cost of construction products was carried out according to the results of constructing regularities of these parameters change. The first step of optimization was to identify the areas of financially effective organizational and technological solutions for the enterprise as a whole. The indicator "profitability" (Y_1) was chosen as the first stage optimization criterion. Those areas were chosen as the effective in which profitability is equal to or more than zero. The second stage of the optimization was to determine the minimum values of the cost of construction products. The search was conducted only in the areas chosen by the first stage of optimization. Namely, in the areas of finance effective organizational and technological solutions.

Fig. 7 contains the results of optimization of the cost of reinforced concrete structures unit (Y_2) influenced by membership of resources used (X_3) and the degree of industriality of applied solutions (X_4) at various values of strategic solutions factors in the management of construction organizations. The analysis of Fig. 7 shows that character of factor X_4 influence differs depending on the level of factor X_1. The use of industrial organization and technological solutions on small sites is impractical, since it increases the cost of reinforced concrete structures arrangement. The minimum value of Y_2 indicator is 3.6 thous. UAN/m^3 when X_1 = 2.2 thous. hours; 3.29 thous. UAN/m^3 – when X_1 = 19.6 thous. hours; 3.14 thous. UAN/m^3 – when X_1 = 37 thous. hours.

The decrease in the optimized indicator is correlated with an increase of "profitability" (Y_1) in all areas of the factor space. The closely placed sites show the highest efficiency of cost of reinforced concrete structures unit in all operating activity of the considered enterprise. The minimum value of cost of reinforced concrete structures unit (Y_2) is equal to:

$Y_{2\,min}$ = 3.14 thous. UAN/m^3 (X_1 = 37 thous. hours; X_3 = 0%; X_4 = 0%).

Eq. (7) represents the dependence of cost of load-bearing metal structures unit (Y_3) from the studied organizational and technological factors:

$$Y_3 = 4576.419 + 8.664X_3 - 0.019X_3^2 - 0.007X_3X_4 - \\ -8.308X_4 + 0.041X_4^2 \quad (7)$$

Let us consider Fig. 8. It graphically shows the optimization of the cost of load-bearing metal structures unit (Y_3) influenced by membership of resources used (X_3) and the industriality of applied solutions (X_4). Analysis of Fig. 8 showed that increasing the level of factor X_3 ("membership of resources used") enhances the average value of indicator Y_3 by 1.14 times; increasing the level of factor X_4 ("industriality of applied solutions") reduces it by 1.1 times. The action of factors meets their organizational and technological sense: attraction of expensive resources increases the cost of installation of metal structures, the use of industrial methods of work reduces the cost of the production process.

The minimum indicator Y_5 value is equal to the following under any strategic decisions of management of the grain storages construction and reconstruction enterprises except the (X_1 = 2.2 thous. hours; X_2 = 550 km):

$Y_{3\,min}$ = 4.16 thous. UAN/ton (X_3 = 0%; X_4 = 100%).

Eq. (8) represents the regularity of change of cost of grain silo storage installation (Y_4) is in analytical form:

$$Y_4 = 82.312 - 2.932X_1 + 0.051X_1^2 - 0.001X_1X_3 + \\ +0.002X_1X_4 + 0.112X_3 - 1.5\times10^{-4}X_3X_4 - 0.126X_4 \quad (8)$$

Eq. (8) showed that enhancing levels of factors X_1 ("average labor input of the projects totality") and X_4 ("industriality of applied solutions") reduces the value of the indicator Y_4; increasing level of factor X_3 ("membership of resources used") increases. Signs of the corresponding coefficients of the formula indicate this.

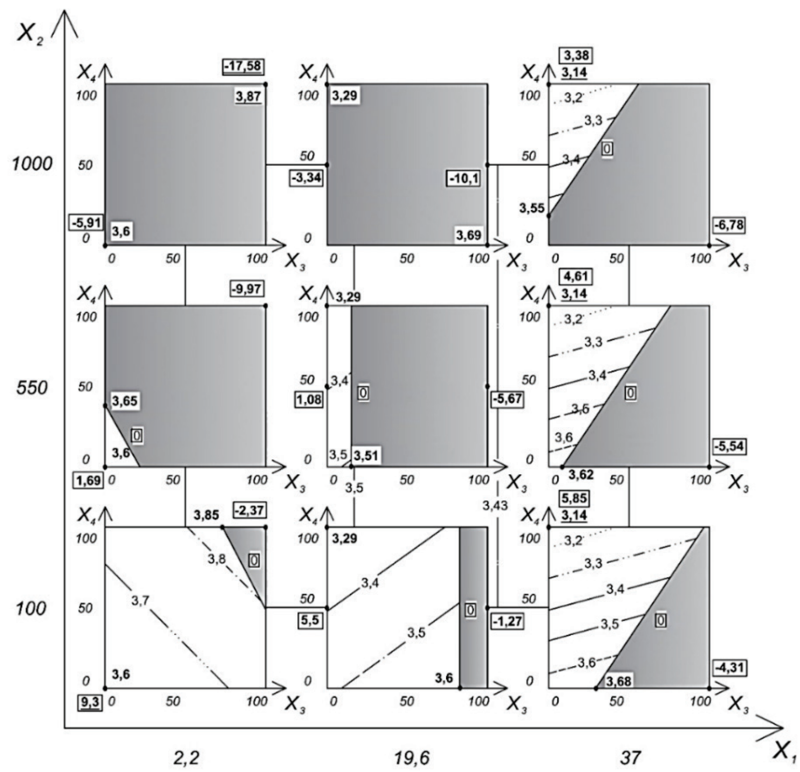

Figure 7 Optimization of cost of reinforced concrete structures unit (Y_2, thous. UAN/m^3) influenced by membership of resources used (X_3, %) and industriality of applied solutions (X_4, %) at various strategic solutions of the enterprise management and under limitation of $Y_1 \geq 0\%$

Fig. 9 contains the results of the optimization of cost of grain silo storage installation (Y_4) under the influence of membership of resources used (X_3) and the industriality of applied solutions (X_4) at different levels of the strategic organizational and technological factors (X_1 and X_2).

The nature of the influence of factors X_3 and X_4 does not change at the different levels of the factor X_1, as Fig. 9 presents. In case of small amounts of work (X_1 = 2.2 thous. hours) membership of resources used (X_3) and industriality of applied solutions (X_4) change indicator Y_4 in the range of 63.8 to 86.88 UAN/m^3 storage; in case of medium amounts (X_1 = 19.6 thous. hours) – from 36.66 to 52.75 UAN/m^3 storage; in case of large amounts (X_1 = 37 thous. hours) – from 34.88 to 43.13-48.02 UAN/m^3 storage (dependent on the level X_2).

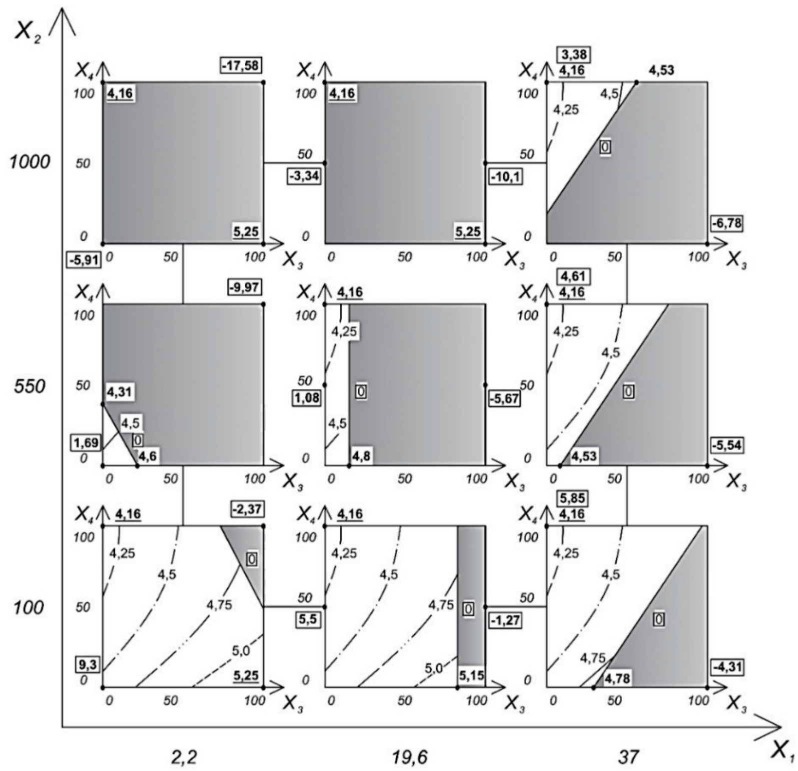

Figure 8 Optimization of cost of load-bearing metal structures unit, Y_3 (thous. UAN/ton) influenced by membership of resources used (X_3, %) and industriality of applied solutions (X_4, %) at various strategic solutions of the enterprise management and under limitation of $Y_1 \geq 0\%$

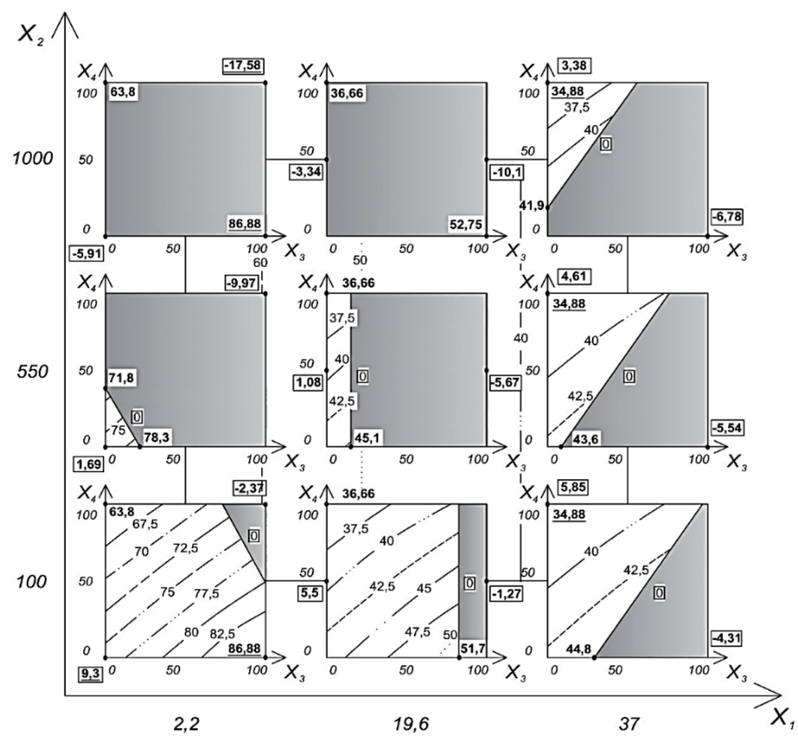

Figure 9 Optimization of cost of grain silo storage installation, Y_4, (UAN/m^3 storage) influenced by membership of resources used (X_3, %) and industriality of applied solutions (X_4, %) at various strategic solutions of the enterprise management and under limitation of $Y_1 \geq 0\%$

Thus, the minimum value of the indicator was achieved at all levels of strategic organizational and technological solutions, except for (X_1 = 2.2 thous. hours; X_2 = 550 km), with the values of two other factors (X_3 = 0%; X_4 = 100%).

A large change of the indicator was observed for the following reasons:

- A significant share of the cost structure for silo storages assembling is occupied by manpower, machines and mechanisms (in the considered model of the enterprise operating activity – 87%). Subcontractors' resources significantly increase the cost of production of such works.

- Proposed industrial solution (usage of hydraulic jacks for wall mounting) greatly optimizes silo installation process by increasing the intensity and the degree of safety of works.

Cost of grain silo storage installation (Y_4) has the minimum value at (X_1 = 0%; X_2 = 100%) in all areas of the space factor, where this restriction does not preclude $Y_1 \geq 0\%$. In this case, the minimum point is still close to these levels of factors.

Eq. (9) presents the change of cost of noria section installation (Y_5) from the organizational and technological factors:

$$Y_5 = 1180.606 + 2.221X_3 - 0.005X_3^2 - 0.002X_3X_4 - -1.461X_4 + 0.011X_4^2 \quad (9)$$

Let us consider Fig. 10. The results of cost optimizing of noria section installation (Y_5) are shown in it graphically.

Analysis of Fig. 10 showed that enhancing the value of factor X_3 increases the average value of indicator Y_5 by 0.17 thous. UAN; increasing the value of factor X_4 – decreases by 0.1 thous. UAN.

The minimum values of indicator levels for all combinations of factors X_1 ("average labor input of the projects totality") and X_2 ("average relocation distance") were observed at the point (X_3 = 0%; X_4 = 100%) and are equal to $Y_{5\,\min}$ = 1.08 thous. UAN/m. Exception is the area at (X_1 = 2.2 thous. hours; X_2 = 550 km). It`s minimum value of indicator "cost of noria section installation" (Y_5) is located at a point (X_3 = 0%; X_4 = 40%) and is equal to $Y_{5\,\min}$ = 1.12 thous. UAN/m.

The regularity of cost changes of conveyor section installation (Y_6) by factors studied is represented in Eq. (10):

$$Y_6 = 844.439 - 0.449X_1 - 0.024X_1^2 + 1.216X_3 - -2.8 \times 10^{-3} X_3^2 - 1.42X_4 + 6.08 \times 10^{-3} X_4^2 \quad (10)$$

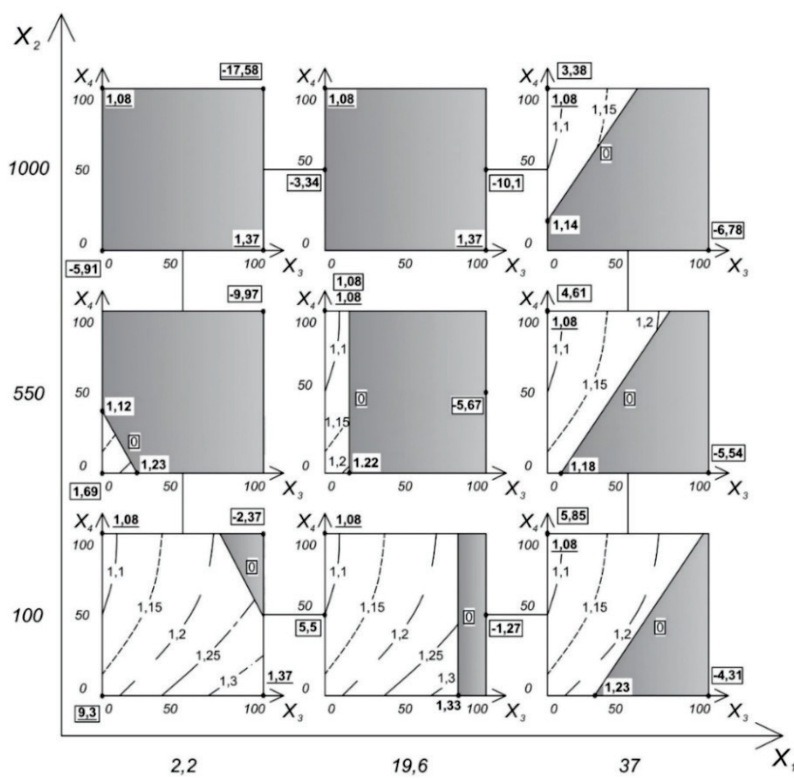

Figure 10 Optimization of cost of noria section installation, Y_5 (thous. UAN/m) influenced by membership of resources used (X_3, %) and industriality of applied solutions (X_4, %) at various strategic solutions of the enterprise management and under limitation of $Y_1 \geq 0\%$

Fig. 11 comprises a graphical representation of the optimization of the cost of conveyor section installation (Y_6) under the influence of membership of resources used (X_3) and the industriality of applied solutions (X_4) for various combinations of levels of the factors "average labor input of the projects totality" and "average relocation distance" (X_1 and X_2).

Analysis of Fig. 11 indicates that the character of the influence of factors X_3 and X_4 on the indicator Y_6 does not change depending on the factor X_1 level. The optimal use of organizational and technological solutions at objects of any size allows to reduce the value of the indicator at 67-156 UAN/m. of conveyor on 9.5-22%.

The minimum value of the indicator Y_6 is at (X_3 = 0%; X_4 = 100%) under any strategic decisions of management of the grain storages construction and reconstruction enterprise than (X_1 = 2.2 thous. hours; X_2 = 550 km).

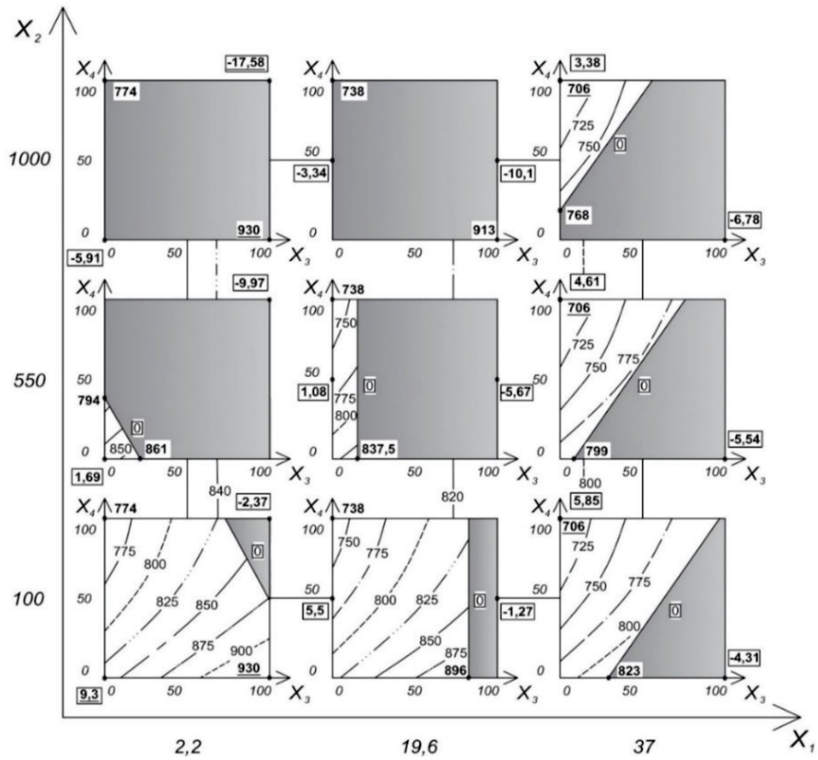

Figure 11 Optimization of cost of conveyor section installation, Y_6 (UAN/m) influenced by membership of resources used (X_3, %) and industriality of applied solutions (X_4, %) at various strategic solutions of the enterprise management and under limitation of $Y_1 \geq 0\%$

7 RATIONALIZATION OF MANAGERIAL DECISIONS OF GRAIN STORAGES CONSTRUCTION AND RECONSTRUCTION

Multidimensional structure, presented in Fig. 4, allows to group projects executed by the organization, depending on their scale (X_1) and territorial diversity (X_2). This makes it possible to analyze organizational and technological interrelationships between similar projects. In the framework of individual projects, different organizational and technological solutions are possible (X_3, X_4). The model shows that there is a connection between the structure of the construction enterprise (DCC) and the management of the construction enterprise (MCE), as well as between the structure (WBS) and the management methods (MCP) of individual projects.

Let us consider examples of companies that have chosen as a development four combinations of strategic organizational and technological decisions:

1. Focusing on objects of a large scale and labor intension, which are located at a considerable distance from each other: MCE $\supset$ {$X_1 \rightarrow$ 37 thousand hours; $X_2 \rightarrow$ 1000 km}.
2. Focusing on small objects located within a limited area: MCE $\supset$ {$X_1 \rightarrow$ 2.2 thousand hours; $X_2 \rightarrow$ 100 km}.
3. Focusing on large and small objects in the ratio of direct costs 75% to 25%: MCE $\supset$ 0,75 {$X_1 \rightarrow$ 37 thousand hours.; $X_2 \rightarrow$ 1000 km} $\cup$ 0,25 {$X_1 \rightarrow$ 2.2 thousand hours; $X_2 \rightarrow$ 1000 km}.
4. Focusing on large and small objects in the ratio of direct costs 25% to 75%: MCE $\supset$ 0,75 {$X_1 \rightarrow$ 2.2 thousand hours; $X_2 \rightarrow$ 1000 km} $\cup$ 0,25 {$X_1 \rightarrow$ 37 thousand hours; $X_2 \rightarrow$ 1000 km}.

In the case of intermediate combinations, the proposed solutions require appropriate adaptation.

For combinations 1, 3, 4, there was selected the biggest value of the factor "average relocation distance" (X_2) as it is the most likely to perform work on various distance in case of an objects totality.

Character of the interactions for each of the strategic combination of organizational and technological solutions contains in Tab. 5. Tab. 6 describes features of the management of enterprises, which construct dispersed different scale buildings, depending on their orientation on own ($X_3 \rightarrow 0\%$) or contracted ($X_3 \rightarrow 100\%$) resources, high ($X_4 \rightarrow 100\%$) or low ($X_4 \rightarrow 0\%$) degree of industrialization of used technological solutions.

The enterprise prepares so that project managers can be recruited from among the existing managers (heads of departments and heads of construction sites) in case of change the organizational and technological conditions, bring them in from outside as needed. In case of unfavorable changes in the organizational and technical conditions, project managers are transferred to the post of heads of departments or construction sites, or their number is reduced.

Analysis of Tab. 5 showed that the main priority for the optimization of the grain storages construction enterprise are: organization of the relevant management system, in-line long-term work performance and optimal scheme of supply.

Table 5 Management interactions between the elements of the enterprise operating activity, which construct grain storages

Connections type	Structure level of the of enterprise	Combinations of strategic organizational and technological solutions			
		1	2	3	4
Vertical	All levels	Senior management has control of project managers and makes strategic decisions. The main center of org. tech. solutions – project management office.	Senior management is involved in the management of all projects and executes them according to the department division of responsibilities.	Senior management has control of project managers and makes strategic decisions. One or more of project managers and their teams manage a portfolio of small projects.	Senior management is involved in the management of all projects and executes them according to the department division of responsibilities. Heads of departments are appointed responsible for major projects.
Horizontal	Group of projects / operating activity as a whole	The management team is formed for each project. The team performs all the functions of engineering, economic and material supplies for the project.	Management of all projects is carried out by departments that perform each of its production function.	Management of portfolio of small projects (multi-project) is assigned to the separate team. Management of large projects is performed according to combination 1.	The workers within the functional departments of the organization are assigned for a large project. The rest of the staff is involved in the projects' management according to combination 2.
	Projects	Participation / non-participation in the project and its linkage with other projects of the organization is measured by the presence of a sufficient number of project management personnel. With a lack of resources, they are involved from outside.	Participation / non-participation in the project and its linkage with other projects of the organization is measured by the presence of labor and / or equipment. Management personnel can be engaged from outside.	The decision on participation / non-participation in the project is carried out according to combination 1. Multi-project in this case is treated as a separate project.	The decision on participation / non-participation in the project is carried out according to combination 2.
	Construction and installation work	It is vital to organize rationally planned engineering workflows within individual projects with their subsequent linkage between projects.	Work is intensified, and slowed down according to the workspace at other sites, in order to develop the company overall continuity of the process flow.	The portfolio of small projects considered as a multi-project with appropriate org. tech. linking work within it. Active flows link large projects and multi-project.	Repeats approach for combination 2. Major project receives priority in the overall enterprise for organizational and technological linking of works.
	Resources	Resources for projects are provided by the project management team. Sharing resources between projects impossible or severely restricted. Sharing human resources and technology available only at the end of their work on the technological flow.	Projects are centrally provided with resources by the department of logistics. Intensive sharing of resources between projects is encouraged. Necessary for specialized work human resources and equipment are transported.	Supply of resources is performed in two ways: individually for each major project and centrally for small projects portfolio. Approaches are combined according to combinations 1 and 2.	Supply of resources is centralized with the priority of major projects.

Table 6 Peculiarities of operating businesses in grain storages construction in the orientation on the different ownership of resources used and industrialization of solutions used

		Attribution of resources (X_3)	
		($X_3 \rightarrow 0\%$)	($X_3 \rightarrow 100\%$)
Industrialization of applied solutions (X_4)	($X_4 \rightarrow 0\%$)	It is appropriate to be involved in small-scale projects, located a short distance from each other. It is required to set qualified contractors, workers and to establish effective systems of operational management. The optimization of logistics methods is critically important. Production functions are distributed between specialized enterprise departments. It is irrational to invest in high-performance engineering and construction machines, because it can be more profitable to draw them from outside.	It is appropriate to be involved in large and medium scale projects at different distances from each other. Management of the work and workers, as well as entire construction projects, should be organized on the principles of engineering. It is of critical importance to create the system of periodic accounting and control the construction works course. Logistical supply may be a duty of the enterprise or responsibility of involved organizations and structures. It is rational to invest in high technology and construction machines.
	($X_4 \rightarrow 100\%$)	It is appropriate to be involved in projects of large and medium scale, at different distances from each other. Qualification of technical staff in the use of effective organizational and technological solutions should be the best. Job function can be organized either by their distribution between the profile departments, and by forming project teams. Using high technology and construction machines requires the creation of depreciation funds.	It is appropriate to be involved in projects of large and medium scale at different distances from each other. Average production functions are efficiently implemented by forming project teams. It is advisable to impose logistical supply on subcontractors. Engineering and technical personnel involved from outside has to be certified in order to perform effective organizational and technological solutions. It may be rational to rent construction equipment and tooling by lease or short lease. It is critically important to create the office of accounting and control the course of construction works and the system of economic accounting and control of operating machinery and equipment. It is mandatory to create depreciation funds.

The algorithm for calculating the income of grain storages construction and reconstruction enterprises is shown in Fig. 12. According to this figure, the general production cost should be calculated in detail, since the cost of these items is different for each individual project. In addition, enterprises shall determine the amount of monthly administrative costs and desired profit level, based on the timing and composition of already implemented construction projects. As a general rule, the longer the lifetime of the project is and the smaller implemented projects are, the greater the level of administrative costs is put in bids on the project. The amount of profit is determined from the same parameters.

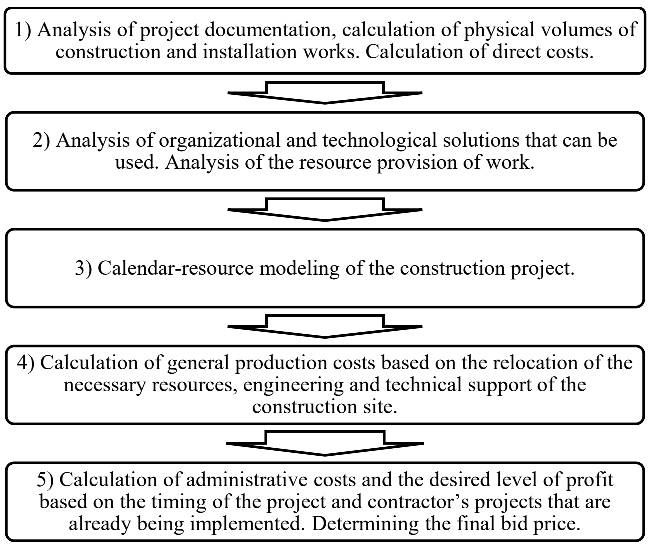

Figure 12 The algorithm for income calculating of grain storages construction and reconstruction enterprises

8 CONCLUSIONS

- Analysis of information sources on the study allowed confirming the high relevance of the present study and justifying the a priori positions.
- The developed method of experimental statistical simulation allowed numerical optimizing of the operating activity of grain storages construction and reconstruction enterprise.
- The proposed model of the operating activity of the grain storages construction and reconstruction enterprise made it possible to theoretically substantiate the link between organizational and technological decisions for the management of individual construction projects and operating activity of the enterprise as a whole.
- The minimum cost of construction products was observed at: X_1 = 37 thous. hours. ("average labor input of the projects totality"); X_2 = 100 km ("average relocation distance"); X_3 = 0% ("membership of resources used"); X_4 = 100% ("industriality of applied solutions"). It is as follows:

- for reinforced concrete structures unit (Y_2) – 3.14 thous. UAN/m^3;
- for load-bearing metal structures unit (Y_3) – 4.16 thous. UAN/ton;
- for grain silo storage installation (Y_4) – 34.88 UAN/m^3 storage;
- for noria section installation (Y_5) – 1.08 thous. UAN/m.;
- for conveyor section installation (Y_6) – 706 UAN/m.

- Designed recommendations are ready for use in order to rationalize the management of companies under consideration.
- The developed method allowed justification of raising of the standard level of income of companies which construct grain storages. The estimated amount of income should be separately justified and fixed in the contract on the basis of the principles of the project management approach.

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Numerical and Experimental Study of the Impeller of a Liquid Pump of a Truck Cooling System and the Development of a New Open-Type Impeller

Rishat Salakhov, Andrey Ermakov, Elvira Gabdulkhakova

Abstract: Typically, closed-type impellers are more efficient than open-type impellers, but in the manufacture of closed-type impellers, cost of wheels is higher. This paper describes the development of cost-effective and simple impeller wheel for a fluid pump in the truck cooling system. To perform this task, the numerical computations of a standard impeller wheel were carried out, its characteristics were also obtained from a test bench, the standard impeller wheel model was verified. The open-type impeller wheel was developed according to the current dimensions of standard impeller wheel and then analyzed with the numerical computations by the software ANSYS CFX (Academic license) computational fluid dynamics. The developed open-type impeller wheel works very effectively in spite of performance degradation by 5% in comparison to the closed-type impeller wheel. When working as a part of engine, the pump efficiency is 0.552-0.579. The maximum value of the pump efficiency is 0.579, it can be achieved at the highest speed of the pump (4,548 rpm and 655 l/min).

Keywords: centrifugal pump; CFD analysis; experimental tests; numerical simulation; optimized design; performance characteristics

1 INTRODUCTION

Reducing CO_2 emissions is an urgent task today. Transport is currently responsible for around a quarter of total greenhouse gas emissions, with road transport representing 17.8% of total emissions, arising from the use of vehicles. The European Automobile Manufacturers Association (ACEA) program has been developed to reduce CO_2 emissions from trucks by 7% by 2025 and 16% by 2030 [1]. One way to reduce CO_2 emissions is to use highly efficient engines. At present, Kama Automobile Plant (KAMAZ PJSC manufacturer located in Naberezhnye Chelny, Russian Federation) is actively developing highly efficient engines, one of which is the 6-cylinder diesel engine to be launched in the nearest future. This engine has reduced CO_2 emissions due to its high power density and efficiency. The increasing power leads to the additional requirement to the cooling system. Today, it is planned to use a pump impeller with a cover disk (closed-type). The closed-type impeller wheel has two disks with blades in between. It creates a good pressure and is characterized by small leaks of water from the exit to the entrance. These impellers are produced in several ways: stamping, casting, spot welding or riveting. Despite the high efficiency, the pump impeller with the cover disk is more difficult to manufacture, which affects the cost of the finished product.

Another area to reduce CO_2 emissions is to reduce emissions from truck production. Commercial vehicle manufacturer MAN Truck & Bus (Germany) has reduced the CO_2 emissions of its production facilities by more than one quarter [2]. The use of a simpler impeller technology for the engine cooling system is also one of the ways to reduce CO_2 emissions, which will also reduce the impeller cost.

Therefore, the main goal of this work is developing the cost-effective and simple impeller wheel with the same high efficiency and pressure. The goal of this engineering research is to design the impeller wheel without the cover disk based on the standard impeller wheel geometry with its external dimensions kept unchanged.

2 MATERIAL AND METHODS

2.1 Research Model

The new open-type impeller wheel was developed according to the methodology generally accepted in Russia [3], which is also in line with the methods accepted worldwide for calculating impeller machines described in [4]. According to the set dimensions, this methodology allows to calculate angles of the flow entry and flow exit to the impeller, as well as the wheel thickness at the entry and exit points. The methodology of numerical calculation is similar to [5].

Initial data for the calculation:

Volumetric flow rate: Q = 500 l/min; Engine speed: n = 3373 rpm; $\omega = \pi n/30$ = 353.220 1/s; Head: H = 18.096 m.

Determination of the main parameters of the blade according to the method given in [1]:

Speed factor: $n_s = 3.65 \cdot n \cdot \frac{\sqrt{Q}}{\sqrt[4]{H^3}}$;

The reduced diameter of the entrance to the wheel: $D_1 = 4.5 \cdot \sqrt[3]{\frac{Q}{n}}$;

Hydraulic efficiency: $n_g = 1 - \frac{0.42}{\left(\log(1000 \cdot D_1) - 0.172\right)^2}$;

Volumetric efficiency: $\eta_V = \frac{1}{1 + 0.68 \cdot \frac{1}{\sqrt[3]{n_s^2}}}$;

Internal mechanical efficiency: $\eta_m = \frac{1}{1 + \frac{820}{n_s^2}}$;

Entry speed: $C_0 = 0.08 \cdot \sqrt[3]{Q \cdot n^2}$;

Blade inlet diameter: $D_0 = \sqrt{4 \cdot \dfrac{Q_{\text{T}}}{\pi \cdot C_0} + d_{\text{CT}}^2}$;

The radial velocity flow at the beginning of blade:

$$C_{1\text{r}} = \frac{C_0}{\psi_1};$$

Initial blade width: $b_1 = \dfrac{Q}{C_{1\text{r}} \cdot \pi \cdot D_1 \cdot \psi_1}$;

Peripheral speed: $U_1 = D_1 \cdot \pi \cdot \dfrac{n}{60}$;

The initial angle of the flow on blades:

$$\beta_1 = \frac{180}{\pi} \cdot \arctan\left(\frac{C_{1\text{r}}}{U_1}\right);$$

End angle of blade flow:

$$\beta_2 = \frac{180}{\pi} \cdot \arcsin\left(C_{2\text{r}} \cdot \frac{\omega_1}{\omega_2} \cdot \frac{\sin\beta_1}{C_{1\text{r}}}\right);$$

Outlet peripheral speed:

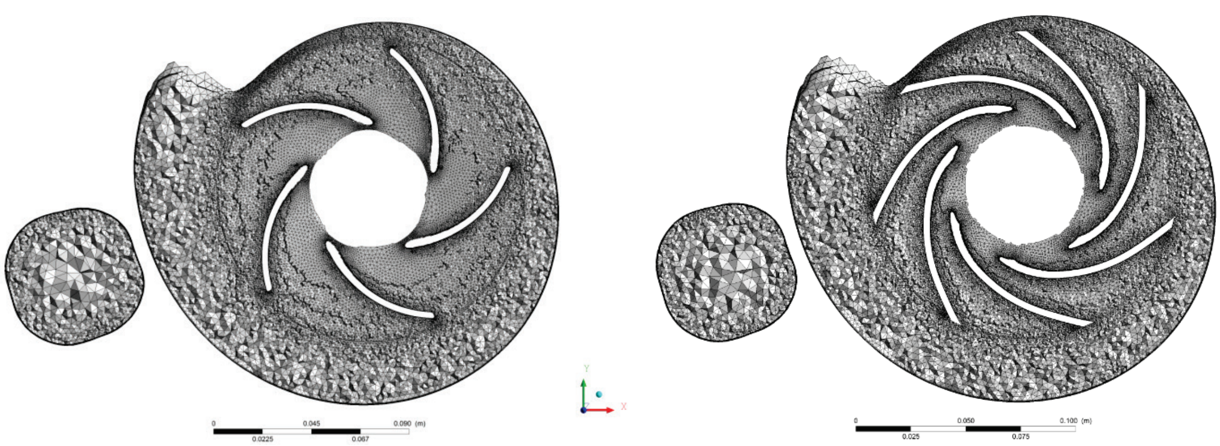
$$U_2 = \frac{C_{2\text{r}}}{2 \cdot \tan\beta_2} + \sqrt{\frac{C_{2\text{r}}^2}{(2 \cdot \tan\beta_2)^2} + 9.81 \cdot H_\infty};$$

Final blade width: $b_2 = \dfrac{Q_{\text{T}}}{C_{2\text{r}} \cdot \pi \cdot D_2 \cdot \psi_2}$.

The original closed-type impeller wheel is shown in Fig. 1 a), and the modified open-type impeller wheel calculated according to the methodology above is shown in Fig. 1 b).

a) b)

Figure 1 Impellers of the liquid pump: a) standard impeller (closed-type) wheel, b) modified impeller (open-type) wheel.



a) b)

Figure 2 Pump mesh section: a) standard impeller wheel, b) modified impeller wheel.

2.2 Creating a Mesh

The mesh is created based on the domain section in the mesh generator software – Ansys Meshing. The hybrid, unstructured mesh consists of tetrahedral and prismatic elements. The prismatic boundary level also consists of seven layers for correct modelling the hydrodynamics of the near-wall flow. Fig. 2 depicts the mesh generated in Meshing software.

The computational model of the liquid pump is created in the Ansys CFX pre-processor based on the generated mesh. The computational model consists of 3 rotor domains and 2 stators coupled through "FLOW - FLOW" interfaces.

The following boundary conditions are determined for this model:

- Working medium is water
- Environmental pressure is 101325 Pa
- Water temperature is 25 °C
- Outlet volumetric flow rate corresponds to the pump-working mode (Tab. 1)
- Atmospheric inlet pressure
- The angle speed of the domain rotation corresponds to the design mode (Tab. 1).

The work modes of the liquid-ring vacuum pump for researching into its hydrodynamic characteristics are listed in Tab. 1.

Table 1 The work modes of the liquid-ring vacuum for researching into its hydrodynamic characteristics

Frequency	Volumetric flow rate	Inlet pressure	Frequency	Volumetric flow rate	Inlet pressure
n, rpm	*Q*, l/min	P_{in}, Pa	*n*, rpm	*Q*, l/min	P_{in}, Pa
1370	80	0	3373	340	0
1370	180	0	3373	500	0
1370	280	0	3373	720	0
1827	130	0	3373	780	0
1827	260	0	3825	370	0
1827	375	0	3825	570	0
1827	450	0	3825	760	0
2732	185	0	4548	3	0
2732	405	0	4548	500	0
2732	565	0	4548	655	0
			4548	760	0

In general, numerical studies of impeller wheels are carried out using k-e turbulence models with Fluent [6, 7] and CFX [8, 9], but this k-e model does not ensure the required calculation accuracy. The k-w turbulence model [10, 11] is also used, which also gives discrepancies [12]. The greatest accuracy is ensured by the Shear Stress Transport (SST) *k-w* turbulence model [13-15] with the accuracy confirmed by a Particle image velocimetry (PIV) study of the flow structure in [4, 16, 17]. The convergence of CFD calculation and experimental studies is up to 10% [18], but the SST *k-w* model allows obtaining high convergence of calculation of 5.1% [6, 19] and 3% [20]. In the model creation stage, the semiempirical model of the k-omega SST turbulence was chosen, since the k-omega SST provides an adequate description of the near-wall turbulence and sensitiveness to the border conditions in the external flow. The authors already have experience in performing similar work when designing a centrifugal pump [21] and modeling heat transfer and hydrodynamics [22], where the k-omega SST model also showed good accuracy.

3 EXPERIMENT

The standard and new impeller wheels were tested for verification of the numerical model.

Figure 4 shows the principal hydraulic scheme of the experimental plant.

The experimental plant provides flow rates from 0 to 800 liters per minute.

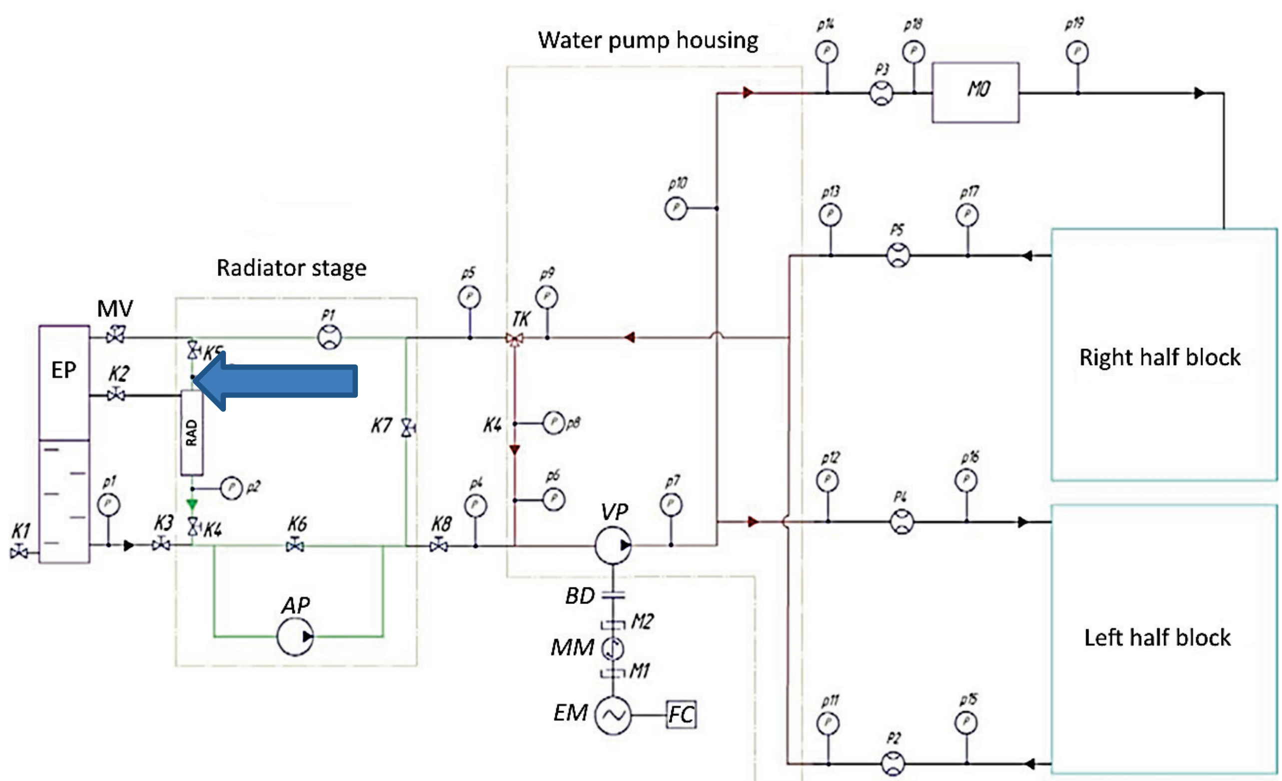


Figure 3 Principal scheme of the hydraulic stand: K1-K8 – globe valve, EP – expansion tank, MV – mixing valve, p1-p19 – pressure transmitter, RAD – cooler, AP – adjustable cradle-mounted pump, TK – thermostat housing, VP – water pump, BD – belt-drive, M1-M2 – compensating clutch, MM – torque sensor, EM – electromotor, FC – frequency convertor, MO – oil cooler, P1-P5 – magnetic induction flow-meter.

4 RESULTS AND DISCUSSION

4.1 Numerical Modeling Results

4.1.1 Standard Impeller Results

The results of numerical modelling determined integral hydrodynamic parameters of the standard impeller wheel in the different work modes: water streamlines in the pump (Fig. 5), velocity vectors in liquid pump section plane (Fig. 6), velocity profile in liquid pump section plane at mode (Fig. 7) and pressure profile in liquid pump section plane (Fig. 8).

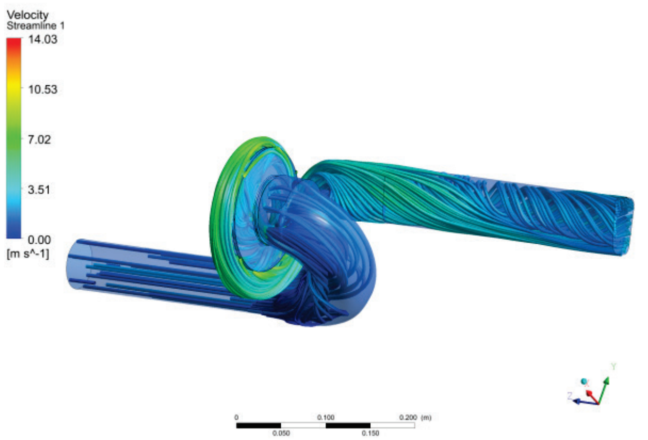


Figure 5 Water streamlines in liquid pump at mode 1827 r/min and 260 l/min

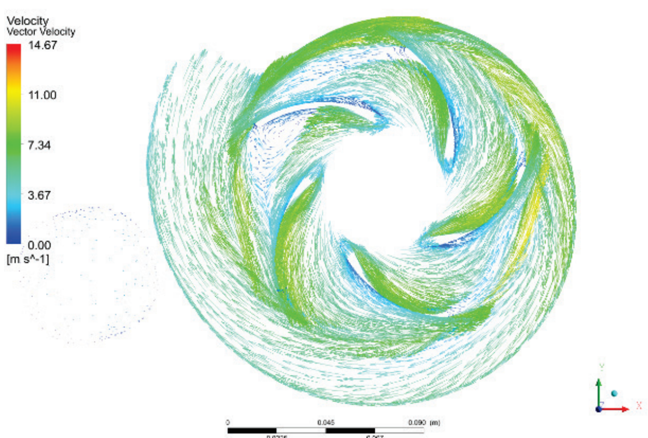


Figure 6 Velocity vectors in liquid pump section plane at 1827 rpm and 260 l/min

The flow structure at the output to the pump is uniform. At the output, you can notice a swirl of the flow, but without obvious flow interruptions, which affects the pump operation.

The cross-section of the pump also shows well-distributed velocity vectors without flow interruptions, but the velocity field shows that flow may disrupt at the end of the blades, which can cause additional flow turbulence and hydraulic losses.

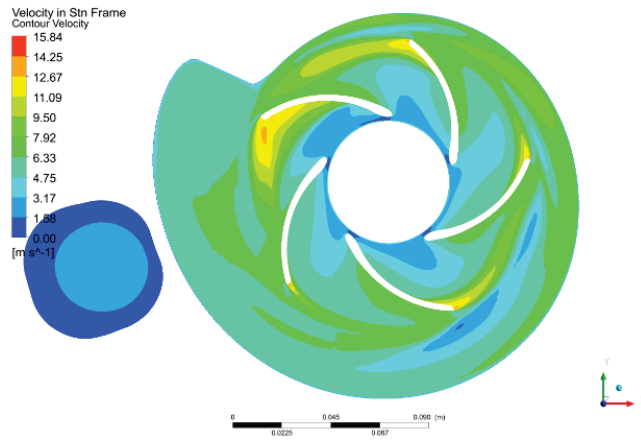


Figure 7 Velocity profile in liquid pump section plane at 1827 rpm and 260 l/min

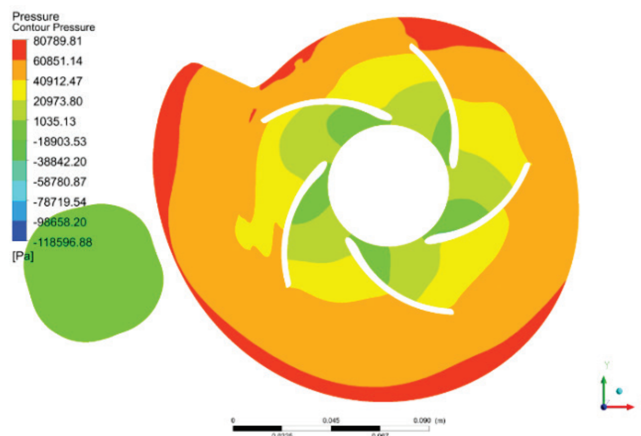


Figure 8 Pressure profile in liquid pump section plane at 1827 rpm and 260 l/min.

The pressure field shows a uniform pressure increase without obvious flow separations.

Table 2 Results of the numerical research of the liquid pump

n, rpm	Q, l/min	h, m	Efficiency	n, rpm	Q, l/min	h, m	Efficiency
1370	80	4.350	0.323	3373	340	23.911	0.537
1370	180	3.620	0.552	3373	500	20.571	0.578
1370	280	2.516	0.518	3373	720	14.172	0.505
1827	130	7.380	0.386	3373	780	11.852	0.447
1827	260	6.170	0.571	3825	370	31.039	0.529
1827	375	4.486	0.522	3825	570	26.287	0.575
1827	450	2.709	0.361	3825	760	20.617	0.545
2732	185	16.584	0.376	4548	3	56.496	0.005
2732	405	13.512	0.577	4548	500	42.322	0.550
2732	565	9.925	0.522	4548	655	37.747	0.579
				4548	760	34.370	0.570

Table 3 Results of the numerical studies of the liquid pump in the engine assembly

n, rpm	*Q*, l/min	*h*, m	Efficiency
1370	180	3.620	0.552
1827	260	6.170	0.571
2732	405	13.512	0.577
3373	500	20.571	0.578
3825	570	26.287	0.575
4548	655	37.747	0.579

In addition, the engine hydraulic characteristic (EHC) was numerically determined.

5 COMPUTATION VERIFICATION AND CONCLUSION

Fig. 9 and Tab. 4 show the comparison results of the numerical calculations and experimental studies. Here we see a good convergence of the numerical and experimental studies results not exceeding 9% in the engine operating modes, which is quite acceptable for this type of work. No further refinement of the numerical model is required.

Table 4 Relative error in the numerical computation of the liquid pump in the engine assembly

n, rpm	*Q*, l/min	*h* (experiment), m	*h* (computation), m	Relative error, %
1370	180	3.581	3.620	0.474
1827	260	6.193	6.170	0.376
2732	405	14.451	13.512	6.483
3373	500	22.083	20.571	6.808
3825	570	28.790	26.287	8.704
4548	655	39.241	37.747	3.820

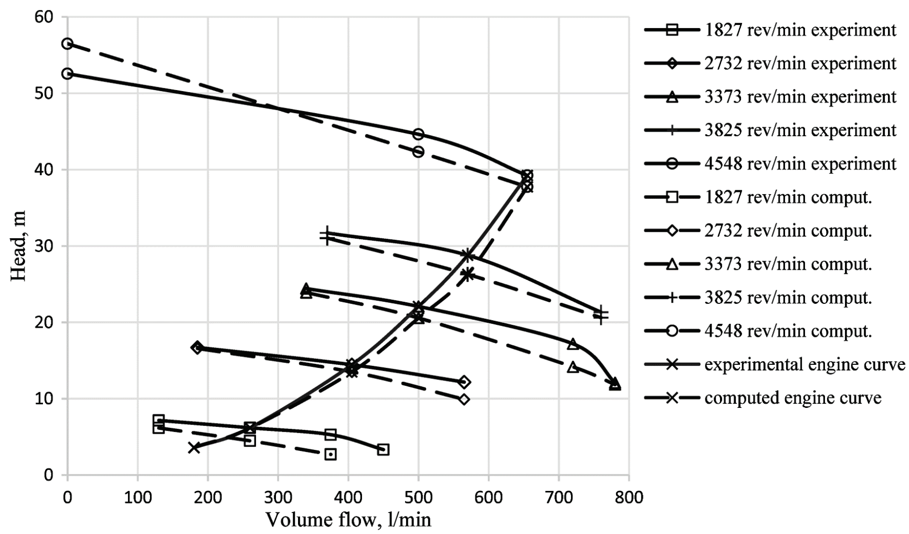


Figure 9 Computed head liquid pump characteristic of the 920.10-700 KAMAZ R6 engine

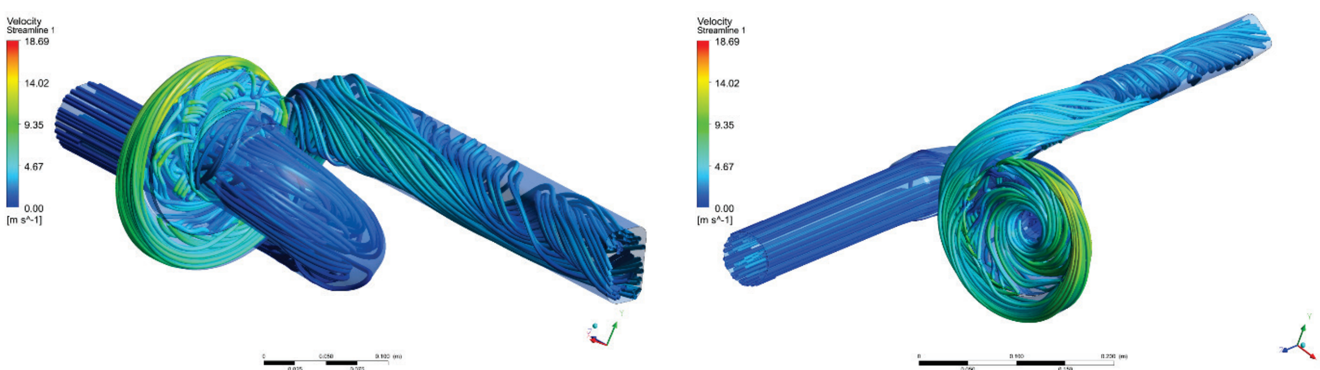


Figure 10 Water streamlines in a liquid pump with the modified impeller at 1827 rpm and 260 l/min

5.1 Modified Impeller Results

Verification of the numerical study and experimental results of the water pump with a standard wheel show the minor error of the computational model. Therefore, this model may be used to test the modified wheel.

The results of numerical modelling determined integral hydrodynamic parameters of the modified impeller wheel at different work modes: water streamlines in the pump (Fig. 10), velocity vectors in liquid pump section plane (Fig. 11), velocity profile in liquid pump section plane (Fig. 12) and pressure profile in liquid pump section plane (Fig. 13).

The flow structure at the pump input is uniform. At the output, you can notice a swirl of the flow without obvious flow interruptions, which affects the pump operation.

Unlike a standard impeller, the speed between the blades of the modified impeller is uniform, which means a more cavitation-resistant design.

The pressure in the modified impeller is increasing even more evenly than that in the standard impeller, which also indicates a good design.

According to the results of the numerical study, the characteristics of the modified impeller are better in the entire range of operation of rotors and fluid flow rates.

Table 5 Results of the numerical study for the liquid pump with the modified impeller

n, rpm	*Q*, l/min	*h*, m	Efficiency	*n*, rpm	*Q*, l/min	*h*, m	Efficiency
1370	80	5.60	0.43	3373	340	30.43	0.25
1370	180	4.60	0.43	3373	500	27.63	0.51
1370	280	3.47	0.60	3373	720	19.45	0.52
1827	130	10.01	0.61	3825	370	40.29	0.57
1827	260	8.07	0.51	3825	570	35.58	0.51
1827	375	6.18	0.40	3825	760	28.21	0.41
2732	185	22.84	0.62	4548	500	54.06	0.54
2732	405	15.13	0.70	4548	655	50.14	0.51
2732	565	13.73	0.40	4548	760	46.37	0.78

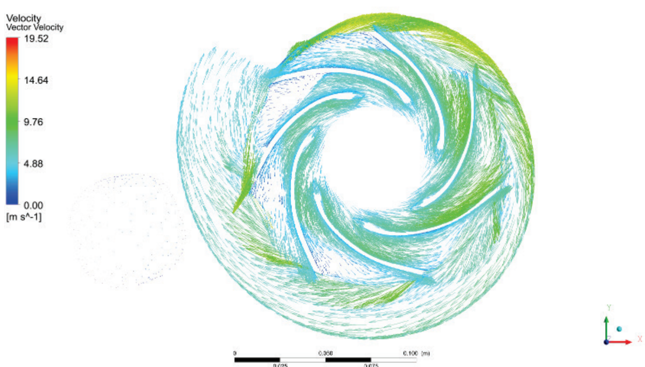


Figure 11 Velocity vectors in liquid pump with the modified impeller section plane at 1827 rpm and 260 l/min

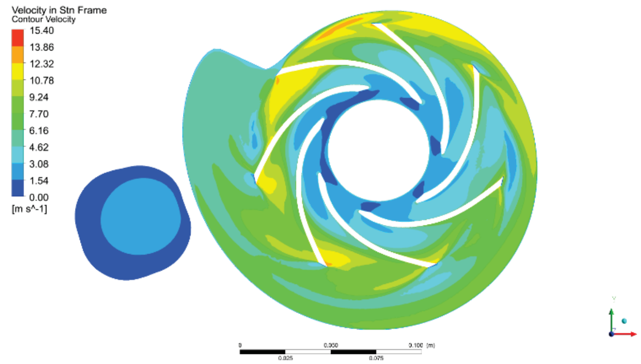


Figure 12 Velocity profile in liquid pump with the modified impeller section plane at 1827 rpm and 260 l/min

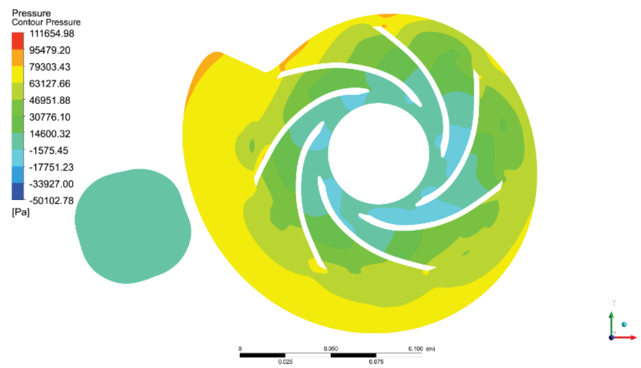


Figure 13 Pressure profile in the liquid pump with modified impeller section plane at 1827 rpm and 260 l/min

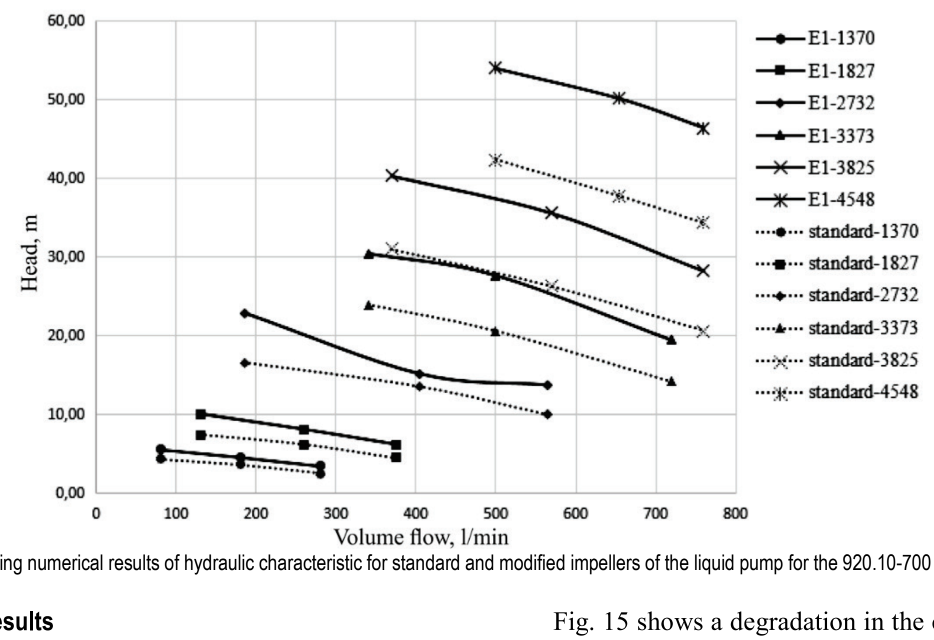


Figure 14 Comparing numerical results of hydraulic characteristic for standard and modified impellers of the liquid pump for the 920.10-700 KAMAZ R6 engine.

5.2 Experimental Results

After manufacturing the plastic modified impeller using the FDM (fused deposition modeling) 3D printing method, it was used for the experimental studies, the results of which are presented in Fig. 15.

Fig. 15 shows a degradation in the characteristics of the modified impeller with an increase in fluid flow, which is possibly associated with the manufacturing technology and an uneven surface that causes additional turbulence.

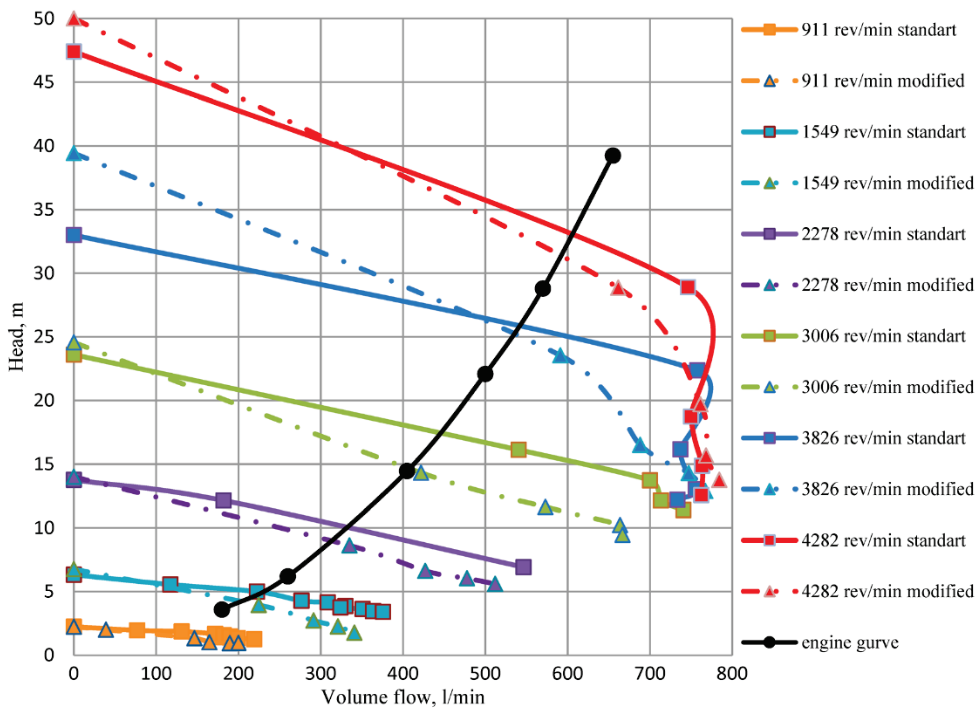


Figure 15 Comparing hydraulic characteristic of the standard and modified impeller

6 DISCUSSION

The verification of the numerical computations with experimental results showed that at the low-pressure values the design values and the experimental values are the same. Based on the results depicted in Tab. 4, the average relative error of the computations is 8.2%. The accuracy of the calculations is a little higher than that in the works [6, 19, 20], but acceptable, and no further refinements of the numerical model are required.

The verification of the numerical computations with experimental results in the engine assembly showed that EHC and the average relative error is the same and equal to 4.45% (Tab. 4).

The investigated liquid pump is highly efficient in the engine assembly. Its efficiency ranges from 0.552 to 0.579. The maximum efficiency value is 0.579 at 4558 rpm and 655 l/min flow rate. These efficiency characteristics are acceptable for open-type impellers, and in our work they are even better than those in the article [4].

The numerical modelling allows to understand the flow distribution inside the pump and how the velocity and pressure (static and absolute) distribute at steady-state and unsteady-state water flow in the flow part. Obviously, taking into account the manufacturing method of FDM 3D printing, these data could not be obtained in the experimental tests, and it is necessary to choose a more expensive, but high-quality printing technology like SLA.

The computational pump model created in Ansys CFX software has been verified successfully. Consequently, it has proved that the software could be used for numerical computations. Numerical tests in the Ansys CFX software allows to optimize the impeller wheel, flow part of the pump, flow part, scroll for improving the 920.10-700 KAMAZ R6 engine pump. As a result, it is possible to improve the power capacity and steady operation of the cooling system of the 920.10-700 KAMAZ R6 diesel engine. In addition, it allows reducing the time and cost of material resources required for creating and optimizing the elements of the engine cooling system.

7 CONCLUSION

The study conducted in this paper suggests the possibility of replacing a closed-type impeller with an open-type wheel with a slight loss of efficiency. The main disadvantage of an open wheel is a low efficiency of about 40%. Closed impellers are 10-15% more efficient than open-type impeller wheels, but also have a higher manufacturing cost. In this work, an open-type impeller wheel was developed directly under the required flow rate and head, which reduced the performance decrease by 5% and overall efficiency is about 57% at nominal flow rate. The manufacture of an open-type impeller is much simpler, simple forms can be used, which also reduces energy costs for the manufacture of molds. The closed-type impeller must be made by casting according to the investment casting only and has complex rods. Starting to use the open-type wheels will significantly reduce CO_2 emissions in wheel casting in the truck production. As for the cost, the open-type wheel is approximately 2 times cheaper.

Acknowledgements

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Original scientific paper

Designing a Sustainable World Class Manufacturing Model in the Automotive Industry in Iran

Zahra Pourvaziry*, Gholamreza Hashemzadeh Khorasgani, Mahmud Modiri, Hassan Farsijani

Abstract: This study is functional in terms of purpose and descriptive-exploratory in terms of doing research. The method of data collection is library and field studies using a questionnaire tool. Those with relevant postgraduate qualifications and at least ten years of working experience, especially management experience in the automotive industry with a sufficiently motivated executive background to participate were chosen. In the quantitative section, the experts include nine executives and senior experts in the automotive industry who were selected through snowballing. The most important dimensions and criteria of a sustainable world class manufacturing model are identified by a theoretical literature review and interviews with the experts, and they were then screened and localized with expert opinions and fuzzy Delphi techniques. After collecting data through a paired comparisons questionnaire, the data were analyzed by using a fuzzy-dimensional network analysis process hybrid technique. The findings of fuzzy DEMATEL indicated that the dimensions of "environmental", "economic" and "social" sustainability help in achieving sustainable world class manufacturing.

Keywords: automotive industry; fuzzy Delphi techniques; fuzzy DEMATEL technique; fuzzy network analysis process; sustainable manufacturing; world class

1 INTRODUCTION

The concept of globalization requires manufacturing companies to strive to manufacture sustainable products with re-engineered technologies, thereby enhancing their competitive advantage in the current market [1]. In this respect, practicing to move along the path of sustainable manufacturing is in fact the hope to achieve profitability, flexibility and positive social and environmental impacts simultaneously. A model of strategic actions for sustainable production can be provided through pure thinking to successfully use sustainable business results. Professional organizations at world-class levels can help empower this path and address barriers through targeted interventions [1]. The concept of sustainable manufacturing emerged at the United Nations Conference on Environment and Development in 1992 and it relates to the concept of sustainable development. It was concluded at the conference that the main cause of the global environmental decline, especially in industrialized countries, is the unstable pattern of manufacturing and consumption. Sustainable manufacturing can be defined as (1) creating goods and services through non-contaminated processes and systems, (2) conservation of energy and natural resources, (3) performing economic and sustainable operations, (4) maintaining a safe and healthy environment for employees, communities, and consumers, and (5) a creative and social reward for employees [32].

Developed countries and world-class organizations are required to implement tangible sustainable development information and awareness in all aspects of people's lives by designing sustainable models [11]. In the industry sector, the focus of sustainable development is on creating projects that can ensure the interaction between the short-term goals of the project and the long-term goals of operating systems while preserving natural resources, the environment and human needs. In this process, optimal utilization of a variety of resources is considered as the main decision-making axis [2].

Implementing sustainable consumption and manufacturing helps reduce future economic, environmental and social costs, while it simultaneously fosters economic competitiveness and reduces poverty, increases productivity, reduces pollution throughout the life cycle and enhances life quality. As such, companies, especially large and transnational corporations, are encouraged to adopt sustainable practices and incorporate sustainable information into their reporting cycle because it is anticipated that by 2030, sustainable practices will be included in the National Priorities Program [11]. The increased demand for sustainable products and services drives the organization to accept innovative concepts that directly affect the life cycle and it causes the organization to move forward in that direction. In the modern era, particular attention is paid in to the manufacturing systems that simultaneously integrate products and services, reduce environmental impacts and create business opportunities for industry, while simultaneously taking into account the social dimensions [3].

Moving towards sustainability makes all organizations and industries more aware of consumption patterns, and companies take responsibility for product life cycle issues. Reaching the highest levels of sustainability is possible when future research focuses on all aspects of the models designed in this area [4]. Indeed, in the concept of sustainability, the goal is to design and understand the concept of sustainable value based on the three key elements of the product, service and system, while simultaneously examining the economic, environmental and social value of each and the type of interaction required for each dimension [3]. The policies adopted for sustainable development are qualitative and realistic, with sufficient information and measurable criteria available for the environmental, social and economic status. Explaining and formulating the criteria that reflect the qualitative characteristics of a society's policies and programs in various economic, social, environmental and other areas in the form of quantifiable and evaluable data is always one of the most important issues and concerns of decision makers, observers and researchers [2].

Iran, along with many other countries, recognized the importance of this and considered the issue of sustainable development as an influential element in the country's political and economic strategies and sought to broaden the focus on achieving sustainable development goals across all arenas. On the other hand, despite close political, cultural and social relations with some neighboring countries, Iran is expected to achieve greater added value and gain a lucrative economic opportunity by identifying and gaining customer expectations in overseas markets and producing high-quality products for sustainable world class manufacturing. In this regard, the automotive company has started operations and exported products to some countries. However, issues and problems such as competitors' high quality products, long service time, poor flexibility in products and services, competitive pricing issues and rising costs, and most importantly, low product innovation have made the industry fail to achieve the expected sustainable competitive advantage. In fact, the development and use of up-to-date technologies is a problem that most of all requires the automotive industry to communicate with the international environment. However, the sanctions also damaged the infrastructure of the industry, and the US exit from the JCPOA, and then the exit of international partners, changed the development plans of domestic companies. Thus, the existence of such issues led a suitable sustainable world class manufacturing model to be presented in the automotive industry in Iran to reach the target markets through export potential and competitive advantage, which can create cost-effective regional export capability.

The questions raised in this study are: What are the dimensions and criteria of a suitable sustainable world-class manufacturing model in the automotive industry in Iran? What is the relationship between the dimensions and criteria? What is the importance of each dimension of the sustainable world class manufacturing?

By defining the dimensions and criteria of the sustainable world-class manufacturing model via the fuzzy Delphi method, the fuzzy DEMATEL technique is used in this study to determine the communications and mutual impact, and the combinational technique of the fuzzy DEMATEL-based network analysis process is used to determine its importance.

2 THEORETICAL FOUNDATIONS AND LITERATURE REVIEW

2.1 World Class Manufacturing

World Class Manufacturing (WCM) is an applied program system that combines the best practices that are compatible with one another so that businesses can continue to operate systematically. WCM is a dynamic model that is evolving and renovating. WCM performance monitoring is also followed by this change [18] .The concept of WCM is a critical process. This proposes a new way to achieve a global status [19]. In today's dynamic and complex environment, organizations and industries compete internationally, and world-class manufacturing of a product is an important element of successful global competition.

Schoenberger was the first to introduce the concept of WCM as follows: it is an extensive agreement on the continuous improvement of quality, cost, waiting time and customer service. He described flexibility as the primary goal of the WCM system. As a result, WCM is at the level of organizational performance that makes possible the ability to compete globally and can respond appropriately to today's business needs [5].

Green [34] provided a more comprehensive definition and said that global benchmarking organizations are the ones which perform best in the world class of related industries. Namely, they are in close contact with their customers and suppliers and are aware of their competitors' performance and they recognize their weaknesses and strengths.

What researchers have in common is that, philosophically, an organization achieves the WCM status when it is able to successfully create productivity capabilities to support the entire organization in achieving a sustainable competitive advantage in the areas of cost, quality, delivery, flexibility, innovation and customer service [6]. The concept of a seven-dimensional WCM can lead to concurrent competitive achievements that can be identified through applying strategies based on the same potentials. WCM is a systematic approach that can manage the criteria for realizing the organization's future progress. In fact, the constant increase in competition makes it possible for each company to review its production processes. There are many different techniques and methods in this path. One of the best optimization techniques is WCM. WCM implementation is a promising issue because it creates a performance measurement system based on the core competencies of organizations which identifies the relationships between the critical factors. Its final output is a good performance measure to help managers make decisions [7].

WCM is a comprehensive term for common methods and effective techniques for delivering desirable high-quality products, timely delivery at full order price and low cost products. Companies dependent on global classification strategies focus on improving operations. This often increases productivity. The WCM framework is based on the effective improvement of quality, cost, delivery and flexibility, which takes time to reach this level [8]. In fact, WCM creates a new paradigm that is rapidly evolving according to the customer needs, and it can guide the organization towards excellence with much flexibility through providing novel and specific solutions with the rapid changes that take place in the markets according to the preferences and volume of production.

2.2 Sustainability

The concept of sustainable production emerged at the United Nations Conference on Environment and Development in 1992 and it is concerned with the concept of sustainable development. It was concluded in the conference that the main cause of the global environmental decline, especially in industrialized countries, is the unstable pattern of manufacturing and consumption. Sustainable manufacturing can be defined as creating goods and services through non-contaminated processes and systems, conservation of energy and natural resources, performing economic and sustainable operations, maintaining safe and healthy environment for employees, communities and consumers and a creative and social reward for employees [5]. On September 17, 2015, the sustainable development goals of the 2030 Program were adopted and implemented from January 2016. They take common global efforts to achieve a sustainable world for all with regard to poverty, inequality, climate change, environmental degradation, welfare, peace and justice on the forefront of all organizations' affairs. Sustainability in manufacturing and service attracted the attention of many business professionals, and several research projects and many related documents were published. Indeed, the sustainability theory and practices in manufacturing became a vital issue in the dynamic business development [9].When sustainability is done successfully, a new strategy approach in order to increase the efficiency and effectiveness in organizational performance is offered [10].

A definition of sustainable development and sustainability that can be agreed upon by the majority encompasses the three main areas of economic, environmental and social development, and the features in each of these sectors are examined [13].

The economic perspective is one of the dimensions of the sustainable development model. Sustainable development is one of the future paths of economic development for each country [11]. A sustainable economic system is able to produce goods or services that reduce the external debt of the government and prevent the imbalance between the various economic sectors while simultaneously protecting the agricultural and industrial production from any damage [6].

Another perspective is the environmental perspective. In general, companies and the environment consistently became two opposing aspects, with any business activity leading to environmental hazards and environmental concerns perceived as a threat to business expansion. However, this conflict gradually diminished with the development and implementation of sustainable green practices in recent years. Organizations and the environment must work together as a team, while organizations play an important role in exploring and assisting technology solutions to solve environmental issues, while the environment plays an important role in creating occupational opportunities and employment [12]. The last perspective of the sustainable development model is the social perspective. Social sustainability is a cultural system [13]. A sustainable social system should be able to achieve equitable distribution of resources and equality of social facilities and services (such as health, gender equality education, political accountability and participation) [14].

3 LITERATURE REVIEW

By surveying sustainable production and consumption in the circular economy, Aravossis [5] explored new concepts of sustainable manufacturing and consumption, and he specifically focused on the economic dimension of sustainability. In the studies of sustainability-based companies focusing on the strategies for greening the workplace, Subbauer & Schafer showed that human resources in organizations have a key role in improving the products and services and developing environmental innovation. Experimental studies of green initiatives and environmental sustainability for small and medium-sized enterprises [12] also indicated that environmental sustainability is appropriate in terms of green practices, green technology policies, process management and supply chain management. Green technology was mentioned in this study [12]. Vinelli & Furlan studied the coexistence between progress and innovation in world-class manufacturing. In this study, it was found that to achieve world-class manufacturing, innovation and improvement initiatives should be simultaneously pursued. Therefore, the commitment to continuous improvement and an impediment to innovation were involved in this way. Additionally, Just in Time (JIT) manufacturing has an impact on world-class manufacturing. The study by DeFelice indicated that the constant increase in competition forces each company to examine its production processes in order to minimize costs and maximize customer service. Moreover, the study by Adel Azar [44] indicated that monitoring and controlling, using high efficiency resources, using high efficiency technology and optimizing the production plan to improve productivity are the key indicators of achieving sustainable production in the refineries. Lanndon Ocampo [45] explored the framework of production strategies in the organizational structure by using the sustainability approach, namely the three economic, social and environmental sectors. In addition, OCAMPO [17] proposed and studied the production and sustainable production strategy with the aim of providing comprehensive guidelines for sustainable development decisions by using the fuzzy hierarchical analysis method [29]. Fosso [23] examined the technology foresight for sustainable production in the German auto supplier industry, in which he introduced environmental sustainability as a new production paradigm and stated that environmental sustainability requires the efficient use of resources and energy. Smith & Ball's research group surveyed the concept of sustainable production in the supply chain to investigate the amount of energy consumed in the supply chain. Winores and Johnson's research group examined the sustainability strategy framework in their model and pointed to market priorities based on this model. The studies by Saloukdar and Seyyed Hosseini [39] pointed to the importance of world-class manufacturing. The results of their study indicated that many companies do their operations without fully understanding the complexity of the relationships between the areas of the manufacturing strategy. Lack of knowledge or lack of explanation of the relationships among the dispersed elements of production in a unified systematic and causal model and not considering time lag led to a departure from the comprehensive model of the world-class manufacturing competitive advantage. The literature reviews and their criticisms are illustrated in Tab. 1.

Table 1 A summary of literature reviews on sustainable world class manufacturing [1]

Researcher	Research results	Focused on:
Antonella [7]	This study explores new concepts of sustainable production and consumption	Focus on the economic dimension among the sustainability dimensions
Stankevi [54]	Achieving organizational	Focus on improving the products and services and

	sustainability by focusing on human resources as well as environmental issues in the production process	on developing environmental innovation based on the role of human resources in organizations
Sari [53]	World-class manufacturing model (WCM) and performance indicators: a comparison between WCM firms	Investigation of WCM Performance and Production Indicators
Muhammad [52]	Production of sustainable products based on reengineering and examining its impact on the environmental, economic and social dimensions	Focus on the environmental and economic dimensions
Jitesh Thakkar [44]	Adoption of green technology in creating environmental sustainability for manufacturing in SMEs	Focus on the environmental dimension
Petrillo [24]	This research objective is twofold: First, providing a "model" to identify factors that influence the core competencies of organizations. Second, proposing a "performance appraisal system" to establish the relationship between the important factors by using WCM	Studying the sustainability dimensions was not the subject of this article
Hernández [29]	General principles of the WCM	Focus on quality
Hernández [29]	Investigating the components of organizational strategic model for achieving WCM - investigating the human-economic and structural components	Studying the sustainability dimensions was not the subject of this article
Kireitinu [3]	Focusing on the production process strategy roadmap with the aim of identifying sustainability and its associated costs in the production process	Proposing other dimensions such as the economy of culture and politics as effective variables – not surveyed
Adel Azar [5]	Investigation of the three dimensions of sustainability – (economic, social and environmental)	Sustainable Production Indicators
Fadley et al. [10]	Investigating the critical success factors of the SMP sustainable manufacturing practices in the Malaysian automotive Industry	Investigation of the social responsibility as the only factor
Mirhabibi [5]	Investigating WCM components, comparing conceptual elements of models	Not reviewing sustainability dimensions
Kireitseu Maxim [30]	Examining WCM dimensions	Production index in WCM
Jain, Bhurchand[26]	Developing the dimensions of a WCM model	Production Indicators in WCM
Andera Chiarini [31]	WCM indicators	Increasing productivity by focusing on new production standards
FCA [25]	A review of the fundamental concepts of WCM in the automotive industry	Not reviewing sustainability dimensions
OCAMPO [17]	Introducing the three dimensions of the economic, social and environmental sustainability	Investigation of the quantitative dimensions of stability
OCAMPO [17]	Reviewing sustainable production strategies	Not reviewing sustainability dimensions
Fösso [33]	Technology forecasting being pivotal to sustainable production in the German automotive supplying industry – the importance of the environmental dimension	Considering the environmental dimension of sustainability as the only dimension
Sarkar [35]	The Impact of WCM Methods on Corporate Performance	Focusing on WCM dimensions
Atkinson [20]	A comprehensive look at the sustainable production framework in the organization	Not reviewing sustainability dimensions
AndreaFurlan [16]	Identifying the Factors Affecting the Implementation of WCM Techniques in the Oil Industry	WCM
Farsijani [5]	Examining WCM indicators	Production Indicators
Heleem et al. [48]	WCM factors	WCM
Heleem et al. [48]	Dimensions of success in WCM	WCM

4 RESEARCH GAP

Undoubtedly, there were many studies on the concepts of sustainability and production in WCM, separately based on literature reviews. However, given the importance of criteria taken from environmental indicators, previous studies were conducted by focusing on this environmental component sector. Additionally, as the world becomes more competitive today, the economic index has a very special place in the models under consideration. The distinguishing feature of the present study is the simultaneous consideration of three sustainability indicators, namely the social, economic, and environmental indicators, which are less common in the studies on WCM.

In the present study, the indicators identified from the literature review are presented and analyzed in Tab. 2. These indicators are identified in the area of sustainability.

Fuzzy DEMATEL is a structural model used to analyze the causal relationship between complex factors. The DEMATEL technique can create a structural map of the system based on the causal relationship [50]. In fact, DEMATEL is a mathematical approach that can be used to analyze the causal dependence and relationship between the dimensions of a problem for complex management and efficient problem solving, and the end result of the

DEMATEL process is a visual demonstration that relies on the graph theory [48]. The ANP process creates complex interdependencies between decision levels and evaluation factors. The level of decision making can be directly or indirectly overcome and influenced by other decision factors and levels using ANP. In the ANP model, human judgments are integrated to compare two factors (sub-factors). Uncertainty in the judgment of decision makers compared to binary factors is significantly reduced. Therefore, the fuzzy ANP method for handling relative uncertainty relative to definitive values emerged [49].

Table 2 Identified indicators in the field of effective sustainability in WCM

Dimension	Criteria	References
Economic	Employment	Kucerova [27]
	Innovation	Muhammad [52]
	Operational costs	Nurul [10]
	Efficiency	Lanndon [46]
	Financial health	Qi, X. [19]
Social	Participating in social events	Peterson, N. D. [14]
	Employee satisfaction	Nurul Fadly [10]
	Empowering Human Capital	Peterson, N. D. [14]
	Respecting civil laws and regulations	Yoo, C. [28]
	Community Health	Kucerova [27]
	Customer satisfaction	Lanndon [46]
Environmental	Environmental pollutants	Muhammad [52]
	Conservation of natural resources	Moultrie, J. [9]
	Use of recyclable raw materials	Yacob [12]
	Using organic raw materials	Lanndon [46]
	Responsiveness	Yoo, C. [28]
	Energy	Atkinson [20]

5 METHODOLOGY

The present study is applied in terms of purpose and it is descriptive-exploratory in terms of doing the research. The data collection method is library studies and is field one. Data collection tool is a researcher-made questionnaire and interviews with experts. The content validity of the questionnaire was assessed through expert opinions. The expert's research community consists of 22 WCM experts, managers and professionals in the field, as well as of university professors. Those with relevant postgraduate qualifications (world class and sustainable development) and at least ten years of working experience, especially management experience in the automotive industry with a sufficiently motivated executive background to participate were chosen. The most important point in determining the experts is the presence of academic experts against professional and empirical experts in order to ensure the consistency of using different perspectives in this research. In the qualitative section, the most important dimensions and criteria of sustainable WCM were identified and partially screened and localized by the fuzzy Delphi method through theoretical literature review and interviews with the experts in which the experts expressed their views on the dimensions and criteria of sustainability of which some were merged, eliminated, added or modified. Moreover, the fuzzy DEMATEL method was used to determine the relationships and the impact of sustainability dimensions and criteria, and the ANP method was used to determine the importance of each dimension and the criteria of sustainability affecting WCM; whereas the ANP method was used with regard to the intrinsic relationship identified by the DANP method between the dimensions and criteria of sustainability. In the study of Lin and Cheng [51], the method was used to solve the fuzzy Delphi problem and the fuzzy DANP problem. The steps of the problem-solving method are listed in the reference section.

Table 3 Screening and survey results of the sustainability criteria affecting the WCM by the fuzzy Delphi method

Dimensions of sustainability	Row	Sustainability Criteria	Non-fuzz average of expert opinions	Questionnaire mean differences	Result
Economical	1	Employment	8.08	0.17	Accepted
	2	Innovation	8.17	0.18	Accepted
	3	Operational cost	8.25	0.17	Accepted
	4	Efficiency	8.16	0.09	Accepted
	5	Financial health	8.41	0.17	Accepted
Social	6	Participating in social events	4.55	0.01	Rejected
	7	Employee satisfaction	8.33	0.17	Accepted
	8	Empowering human capital	8.33	0.17	Accepted
	9	Respecting civil laws and regulations	8.49	0.17	Accepted
	10	Community health	8.00	0.18	Accepted
	11	Customer satisfaction	8.00	0.18	Accepted
Biological	12	Reducing environmental pollutants	8.17	0.09	Accepted
	13	Conservation of natural resources	8.08	0.17	Accepted
	14	Using recyclable raw materials	8.41	0.17	Accepted
	16	Responsiveness	8.33	0.17	Accepted
	17	Energy	8.33	0.17	Accepted

6 DATA ANALYSIS

In this study, the dimensions and criteria of sustainability affecting a sustainable WCM were identified by a theoretical review of literature and various articles, as well as interviews with the experts. Furthermore, localization and screening were performed by using the fuzzy Delphi method through interviews with twenty two experts. After collecting the data and solving it by using the fuzzy Delphi method in three stages, the criteria in which the experts' disagreement at different stages was below the threshold of 0.2 and their mean score was more than 8 were finally chosen after collecting data by the fuzzy Delphi method. The screening results are summarized in Tab. 3.

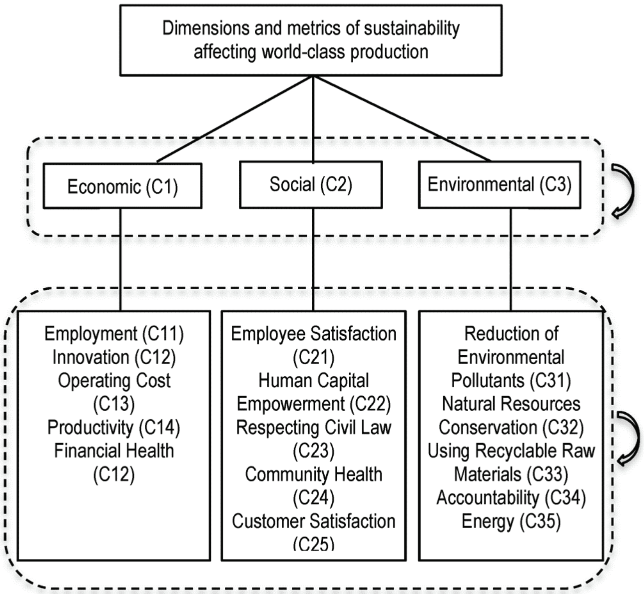

Figure 1 The model and network structure of the research on the sustainable WCM [1]

Fig. 1 illustrates the network structure model of the dimensions and measures of sustainability affecting WCM. In this chart, the relationships between all dimensions and criteria are considered.

Since the second question of the research is what the relationships between the sustainability dimensions and criteria and their effects on each other in WCM are, the DEMATEL method was used to answer this question. To this end, nine experts from the automotive company measure responded to the impact of each sustainability dimension and criteria on the spectrum of very high impact (4), high impact (3), low impact (2), very low impact (1), and without impact (0). Therefore, a fuzzy direct relation matrix for sustainability dimensions (Tab. 4) and criteria (Tab. 5) was formed after collecting the data and aggregating the views by using the arithmetic mean.

Table 4 Fuzzy integrated direct relationship matrix of sustainability dimensions

	Economical			Social			Environmental		
	Upper bound	Middle bound	Lower bound	Upper bound	Middle bound	Lower bound	Upper bound	Middle bound	Lower bound
Economical	(0, 0, 0)			(0/5, 0/75, 0/917)			(0/714, 0/667, 0/917)		
Social	(0/5, 0/75, 0/917)			(0, 0, 0)			(0/25, 0/5, 0/75)		
Environmental	(0/417, 0/667, 0/917)			(0/333, 0/583, 0/833)			(0, 0, 0)		

Table 5 Fuzzy integrated direct relationship matrix of the sustainability criteria

C	C_{11}	C_{12}	C	C_{34}	C_{35}
C_{11}	(0, 0, 0)	(0/3, 0/45, 0/65)	…	(0/25, 0/4, 0/6)	(0/25, 0/4, 0/65)
C_{12}	(0/3, 0/45, 0/65)	(0, 0, 0)	…	(0/25, 0/4, 0/65)	(0/35, 0/5, 0/7)
C_{13}	(0/2, 0/35, 0/6)	(0/25, 0/4, 0/65)	…	(0/1, 0/2, 0/45)	(0/2, 0/35, 0/6)
C_{14}	(0/3, 0/45, 0/65)	(0/5, 0/45, 0/7)	…	(0/2, 0/35, 0/6)	(0/35, 0/5, 0/7)
C_{15}	(0/35, 0/5, 0/7)	(0/3, 0/45, 0/65)	…	(0/2, 0/3, 0/65)	(0/2, 0/3, 0/5)
C_{21}	(0/35, 0/5, 0/7)	(0/3, 0/45, 0/7)	…	(0/4, 0/55, 0/7)	(0/3, 0/45, 0/65)
C_{22}	(0/35, 0/5, 0/7)	(0/25, 0/4, 0/65)	…	(0/25, 0/4, 0/65)	(0/2, 0/35, 0/6)
C_{23}	(0/15, 0/3, 0/55)	(0/15, 0/3, 0/55)	…	(0/2, 0/3, 0/55)	(0/15, 0/25, 0/5)
C_{24}	(0/125, 0/25, 0/5)	(0/25, 0/4, 0/65)	…	(0/125, 0/25, 0/5)	(0/25, 0/37, 0/62)
C_{25}	(0/3, 0/45, 0/65)	(0/18, 0/31, 0/56)	…	(0/25, 0/4, 0/65)	(0/1, 0/25, 0/5)
C_{31}	(0/25, 0/4, 0/65)	(0/15, 0/3, 0/55)	…	(0/2, 0/35, 0/6)	(0/3, 0/45, 0/7)
C_{32}	(0/35, 0/5, 0/7)	(0/2, 0/35, 0/6)	…	(0/1, 0/2, 0/45)	(0/25, 0/4, 0/65)
C_{33}	(0/35, 0/5, 0/7)	(0/25, 0/4, 0/65)	…	(0/1, 0/25, 0/5)	(0/25, 0/4, 0/65)
C_{34}	(0/3, 0/45, 0/7)	(0/2, 0/35, 0/6)	…	(0, 0, 0)	(0/2, 0/3, 0/5)
C_{35}	(0/25, 0/4, 0/65)	(0/4, 0/55, 0/7)	…	(0/2, 0/35, 0/6)	(0, 0, 0)

Note: This matrix is compressed due to the large size of the matrix 15×15 and the lack of screen space.

Table 6 Matrix of fuzzy general relationships among the sustainability dimension

	C_1	C_2	C_3
C_1	(0/17, 0/73, 7/29)	(0/98, 1, 7/41)	(0/32, 0/91, 7/18)
C_2	(0/37, 0/97, 7/17)	(0/14, 0/65, 6/64)	(0/24, 0/80, 6/72)
C_3	(0/33, 0/73, 7/41)	(0/3, 0/89, 7/18)	(0/17, 0/89, 6/64)

In the next step, the normalized matrix was calculated for the dimensions, and the criteria of sustainability affecting WCM and the fuzzy general relations matrix ($\widetilde{\boldsymbol{T}}$) were obtained by multiplying the normal matrix in the inverse matrix after subtracting the fuzzy direct relation matrix from the normal matrix and calculating the inverse matrix. Tab. 6 illustrates the general relations matrix for the dimensions and Tab. 7 illustrates the sustainability criteria affecting WCM.

Finally, to determine the relationships, the effect value ($\widetilde{D}$) is obtained from the sum of the rows, the impact of ($\widetilde{R}t$) is obtained from the sum of columns, the significance ($\widetilde{D}+\widetilde{R}$) and the net fuzzy effect ($\widetilde{D}-\widetilde{R}$) on the dimensions and the criteria of sustainability affecting WCM that are given in Tab. 8.

Based on Tab. 8, the "environmental" dimension is the most effective one with the highest impact / impressiveness of 0.295 and the "social" dimension was the most impressive one with the least net impact / impressiveness of -0.293. Among the environmental criteria, the criterion of the "reduction of environmental pollutants" is the most effective and the "protection of natural resources" is the most impressive criteria. Among the economic criteria, "innovation" has the most impact and the "operating cost" has the most impressiveness. Finally, among the social criteria, the criterion of "employee satisfaction" has the most impact and the criterion of "customer satisfaction" is the most impressive criteria in WCM.

Table 7 Matrix of fuzzy general relationships among the sustainability criteria

C	C_{11}	C_{12}	C	C_{34}	C_{35}
C_{11}	(0/021, 0/07, 1/04)	(0/05, 0/11, 1/08)	…	(0/041, 0/1, 0/98)	(0/044, 0/11, 1/04)
C_{12}	(0/052, 0/12, 1/13)	(0/019, 0/07, 1/04)	…	(0/041, 0/1, 1/10)	(0/054, 0/12, 1/07)
C_{13}	(0/033, 0/09, 0/95)	(0/037, 0/09, 0/93)	…	(0/019, 0/06, 0/83)	(0/031, 0/08, 0/89)
C_{14}	(0/048, 0/11, 1/08)	(0/047, 0/11, 1/07)	…	(0/034, 0/09, 0/96)	(0/051, 0/11, 1/03)
C_{15}	(0/055, 0/12, 1/03)	(0/049, 0/11, 1/01)	…	(0/035, 0/08, 0/9)	(0/037, 0/09, 0/96)
C_{21}	(0/059, 0/13, 1/14)	(0/057, 0/12, 1/12)	…	(0/058, 0/12, 1/02)	(0/05, 0/11, 1/07)
C_{22}	(0/054, 0/12, 1/09)	(0/042, 0/1, 1/06)	…	(0/039, 0/09, 0/97)	(0/036, 0/09, 1/02)
C_{23}	(0/034, 0/1, 1/06)	(0/032, 0/09, 1/03)	…	(0/034, 0/08, 0/94)	(0/031, 0/08, 0/99)
C_{24}	(0/03, 0/09, 1/02)	(0/041, 0/1, 1/01)	…	(0/025, 0/08, 0/91)	(0/04, 0/09, 0/98)
C_{25}	(0/047, 0/11, 1/04)	(0/034, 0/09, 1/01)	…	(0/038, 0/09, 0/93)	(0/024, 0/08, 0/97)
C_{31}	(0/045, 0/11, 1/11)	(0/034, 0/1, 1/08)	…	(0/035, 0/09, 0/99)	(0/048, 0/11, 1/05)
C_{32}	(0/055, 0/12, 1/09)	(0/038, 1/0, 1/05)	…	(0/024, 0/07, 0/95)	(0/042, 0/1, 1/02)
C_{33}	(0/056, 0/12, 1/11)	(0/044, 0/11, 1/08)	…	(0/025, 0/08, 0/97)	(0/043, 0/1, 1/04)
C_{34}	(0/049, 0/11, 1/07)	(0/037, 0/1, 1/04)	…	(0/013, 0/05, 0/89)	(0/036, 0/09, 0/99)
C_{35}	(0/045, 0/11, 1/11)	(0/058, 0/12, 1/09)	…	(0/035, 0/09, 0/99)	(0/016, 0/06, 0/98)

Note: This matrix is compressed due to the large size of the matrix15×15 and the lack of screen space.

Table 8 Interaction and order of the impact /impressiveness value of effective sustainability dimensions and the criteria on WCM

Sustainability dimension	Interaction values	The order of net impact / impressiveness	Result	Sustainability criteria	Interaction values	The order of net impact / impressiveness	Result
Biological	15/96	0/295	Effective	Reducing environmental pollutants	3/767	0/086	Effective
				Responsiveness	3/581	0/045	
				Using recyclable raw materials	3/778	0/006	
				Energy	3/819	-0/0062	Impressive
				Conservation of natural resources	3/809	-0/131	
Economical	16/93	-0/002	Impressive	Innovation	4/047	0/174	Effective
				Employment	4/055	0/091	
				Efficiency	3/999	0/02	
				Financial health	3/931	-0/043	Impressive
				Operational cost	3/744	-0/242	
Social	16/1	-0/293		Employee satisfaction	4/046	0/184	Effective
				Respecting civil laws and regulations	3/86	0/053	
				Community health	3/812	-0/015	Impressive
				Empowering human capital	4/027	-0/08	
				Customer satisfaction	3/917	-0/142	

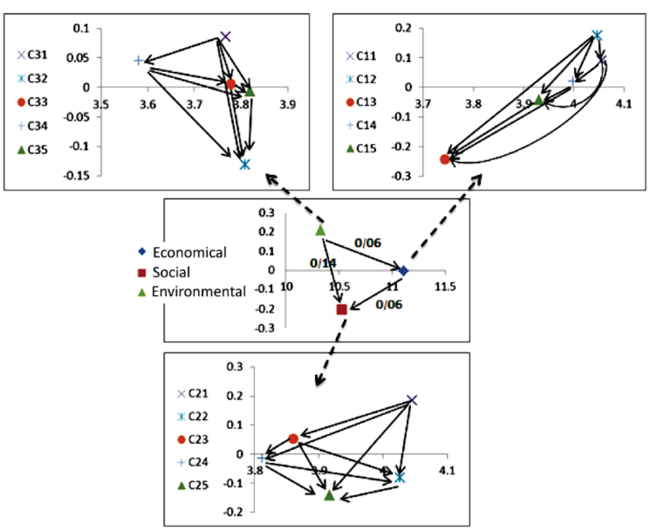

Figure 2 Network Map Relationship between Sustainability Dimensions and the Criteria Affecting WCM [2]

Finally, the fuzzy general relations matrix is used to delineate the Network Relations Map (NRM). Fig. 2 illustrates the NRM for the dimensions and the criteria of sustainability affecting WCM, in which the interactions and the direction of impact between the dimensions and criteria are specified. As Fig. 2 shows, the "environmental" dimension affects 6% on the "economic" dimension and 14% on the "social" dimension. This result indicates that the impressive dimensions are improved to the percentages specified by a one percent increase in the "environmental" dimension. Additionally, the "economic" dimension affects the "social" dimension by 6%. Based on this result, the "social" dimension improves by 6% through increasing one percent of the "economic" dimension.

Based on Fig. 2, the social dimension is the most influential one that needs to be improved for WCM. Based on this result, governments and organizations can achieve WCM through improving social indicators. Managers and policy makers at the strategic level can focus on the environmental dimension (which is most effective) to improve the "social" dimension and improve the social dimension through the "environmental" and "economic" dimensions. At the operational level, managers also focus on the social criteria. To this end, it is necessary to improve "customer satisfaction" (most effective) through "employee satisfaction" (most effective). "Operating costs" and "financial health" should be improved through the "innovation" criteria to improve the "economic" dimension; because according to the relationship network map, the criteria of the "operating cost" and "financial health" are the most impressive and the "innovation" criteria are the most effective criteria.

More attention needs to be paid to the "conserve natural resources" criterion in order to meet the "environmental" criteria in WCM, since environmental dimension was the most impressive. In other words, environmental success depends on the "conservation of nature" criterion, which is improved by "reducing environmental pollutants". Therefore, managers can focus on the criterion of "reducing environmental pollutants" to achieve and improve the "conservation of natural resources".

Table 9 Weight and Importance of Dimensions and Criteria for Sustainability Affecting WCM

Dimensions of sustainability		Sustainability Criteria	Weight and the relative importance of sub-factors	The final weight and importance of sub-factors
Economic C_1	(1) 0/356	Employment	(4) 0/199	(6) 0/0709
		Innovation	(5) 0/187	(7) 0/0667
		Operational cost	(1) 0/208	(1) 0/0741
		Efficiency	(3) 0/2	(5) 0/0713
		Financial health	(2) 0/205	(2) 0/0732
Social C_2	(2) 0/337	Employee satisfaction	(3) 0/196	(8) 0/0661
		Empowering Human capital	(1) 0/214	(3) 0/0723
		Respecting civil laws and regulations	(5) 0/185	(12) 0/0626
		Community health	(4) 0/192	(10) 0/0649
		Customer satisfaction	(2) 0/212	(4) 0/0714)
Environmental C_3	(3) 0/307	Reducing environmental pollutants	(4) 0/193	(14) 0/059
		Conservation of natural resources	(1) 0/212	(9) 0/065
		Using recyclable raw materials	(3) 0/198	(13) 0/0608
		Responsiveness	(5) 0/188	(15) 0/0578
		Energy	(2) 0/208	(11) 0/0639

Hence, to obtain the importance of each dimension and the criteria of sustainability affecting WCM, the fuzzy ANP method was used to calculate the weight to determine the significance. In this study, the fuzzy ANP [45] is solved based on the general relations matrix in the fuzzy DEMATEL method. In this section, the DEMATEL general relations matrix was first normalized and the balanced fuzzy super matrix was obtained. The balanced super matrix is converged through the equation $\lim_{K\to\infty}(W^{\alpha})^K$ in the power of 9-5 digits and the limit matrix was formed. Finally, the weight of the dimensions and the criteria of sustainability affecting the WCL were identified and the degree of significance was obtained through obtaining the boundary super matrix and its defuzzification by the gravity center method (Tab. 9).

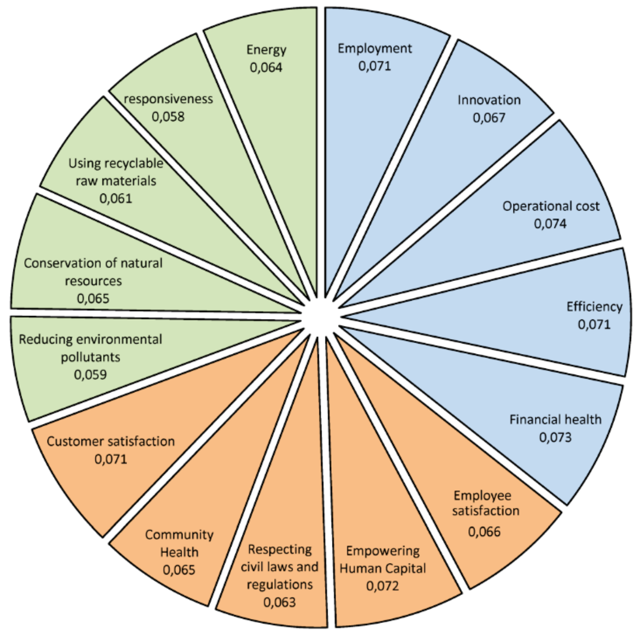

Figure 3 Sustainable WCM model [3]

As Tab. 9 illustrates, the majority of the weight is related to the "economic" dimension that has the most impact on WCM. The "operating cost" criterion with the highest relative weight of 0.220 has the greatest impact on the sustainable WCM. "Empowering human capital" in the social dimension of 0.221 has the most significance in achieving the sustainable WCM. The conservation of natural resources, with a weight of 0.221, is one of the top priorities in the environmental dimension for achieving the sustainable WCM. Based on the results in Tab. 9, Fig. 3 illustrates the sustainable WCM model.

6 CONCLUSION AND RECOMMENDATIONS

Today, governments, international organizations, and support groups have made great efforts to enable human societies to sustainably do business due to lack of resources and environmental protection. The present study aimed to design a sustainable WCM model in which the dimensions and criteria of sustainability were selected by the fuzzy Delphi method and then, its importance was determined in the model by the fuzzy DANP method. In this model, managers can focus on designated relationships and impact / impressiveness for improvement.

According to the research findings, the "economic" dimension at the strategic level is of the utmost importance and has the most impact on the sustainable WCM. This result indicates that managers and policymakers should focus more on the "economic" dimension of achieving the sustainable WCM. If the organization improves its economic benchmarks, the sustainable WCM is expected to improve. Based on the results, it is necessary to plan on the "environmental" dimension (most influential) and it should be a part of the improvement priorities and attention should be paid to how it is communicated in order to improve the economic dimension. Moreover, analyzing the relationships between the economic criteria can improve this criterion. Accordingly, the "operating costs" and "financial health" criteria are improved through the "innovation" criteria. It is therefore recommended that managers create guidelines for innovation in the automotive industry and prepare the environment and context for it.

The "operating cost" criterion has the most impact on the sustainable WCM at the operational level. This result indicates that high reliability, responsive, flexible production and the production based on customer needs can be achieved through controlling and reducing operating costs such as waste, duplications, breakdowns, energy and other costs. For example, an organization can reduce waste, mistakes, and duplications by increasing staff skills, software programs, and statistical quality control. Therefore, it is recommended that the organization identifies operational costs that lead to the waste of resources, and that they take measures to control and reduce it.

The "financial health" criterion is the second priority in achieving the sustainable WCM in terms of importance. This result indicates that the criterion of "financial health" is also one of the most important cases in the sustainable WCM. Financial health is the ability to add the value of the capability and the continuity of business activities in organizations and can prevent bankruptcy, because the performance of business units can be analyzed and evaluated through financial reports and financial ratios analyses. Therefore, managers can identify their weaknesses and strengths by presenting historical financial reports and they can achieve sustainable production by creating improvement plans. Furthermore, the "operating cost" and "financial health" criteria have the most impact on the economic dimension, focusing on the most effective and the most efficient factor (innovation) to improve and control their effectiveness in order to prevent failure. Decision makers are recommended to improve "operating costs" and "financial health" through innovations in economic activities, including the use of new and innovative methods and tools such as artificial intelligence tools and production methods.

The "Human Capital Empowerment Criterion" is the third priority of the sustainable WCM model. It is considered that human resources that can help organizations succeed in producing the sustainable WCM are the most valuable asset of an organization. Therefore, one of the most effective ways to achieve the sustainable WCM is expected to be human resource development and empowerment. It is suggested that managers achieve quality production, competitive prices, appropriate after-sales service, and WCM delivery by developing and empowering human resources through improved skills, knowledge and motivation. Based on the identified relationships, the human capital empowerment leads to customer satisfaction and influences it. Since the present study was conducted at a state-owned automobile company with specific features and structure, it is expected that the findings of the present study would not be generalizable to other similar companies and other industries; therefore, it is recommended that researchers conduct the present research in other organizations in order to realize its comprehensiveness.

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Original scientific paper

Placement and Quantitating of FACTS Devices in a Power System Including the Wind Unit to Enhance System Parameters

Amir Bagheran Sharbaf*, Ali Asghar Shojaei

Abstract: One of the main concerns of network operators is the enhancement of system parameters; accordingly, a set of different means to this end are posed. However, the use of renewable energies such as the wind could increase the importance of the debate over sustainability and conditions of power system parameters. In this study, the condition of said parameters is examined by placing FACTS (Flexible Alternating Current Transmission System) devices in a 24-bus power system including a wind farm. Research data entailing information on the wind and the amount of consumption load per year are classified by using the K-means classification algorithm; then, the objective function is obtained according to the parameters intended for optimization. This function is optimized by using the Honey-bee mating optimization (HBMO) algorithm followed by obtaining the suitable place and amount for FACTS devices. The results showed that the examined parameters are optimized when using FACTS devices.

Keywords: FACTS devices; HBMO algorithm; K-Means algorithm; system's parameters

1 INTRODUCTION

One of the criteria of industrial countries is their extent of electric energy production. The amount of energy production and consumption is a suitable criterion to assess the welfare level. Subsequently, it is of substantial importance to provide stability and sustainability to the production of this type of energy. The sustainability of the power system and the voltage and reduction of costs are the most significant concerns of operators. A lack of attention to system parameters would impose considerable expenses on the network caused by network unsustainability, voltage collapse and large-scale blackouts in the network; unquestionably, putting an end to this situation is costly, requires time and may result in severe damages. A solution to this problem is to increase the production of the network, which is possible through building new production units, though it requires considerable costs. Another solution is to employ the methods of increasing the network capacity, which not only enhances network parameters, but also prevents spending significant costs on building new production units. In previous studies, FACTS devices were used to reduce system parameters. In [1], the power flow was controlled by using FACTS devices in a 9-bus system. In [2], voltage sustainability and the load-flow were improved. The Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) were employed to increase the sustainability of the power system and to reduce losses [3]. Sustainability increase and production cost reductions were examined by using an innovative optimization algorithm in 9 and 39-bus test systems [4]. In [5], in order to decrease the system losses and improve the voltage profile, the test was performed on a 30-bus system. What is worth pointing out in previous studies is the fact that the majority of inquiries were focused on the optimization of one, or at most, two objectives, while the examined networks did not include wind units. Nonetheless, the network investigated in the present study is an IEEE standard 24-bus test system, intended for the optimization of several parameters simultaneously. The honey-bee mating optimization algorithm could be considered as a general method of optimization based on the behavior of insects. In this study, the objective function which includes the parameters in question is optimized by using the HBMO method, the results of which would provide thorough information.

2 FACTS DEVICES

FACTS devices is capable of consistently controlling the load-flow, minimizing costs, increasing sustainability, altering the reactive power according to system requirements and increasing transferability. The modelling of FACTS devices is done as a series, parallel, or series-parallel. The FACTS devices used in this study are described in the following text.

2.1 SVC (Static VAR Compensator)

SVC is a compensator controlled by using a thyristor; it is a pioneering element in the area of FACTS controls which became prevalent in the late 1970s. SVC is placed in a circuit as parallels (Fig. 1).

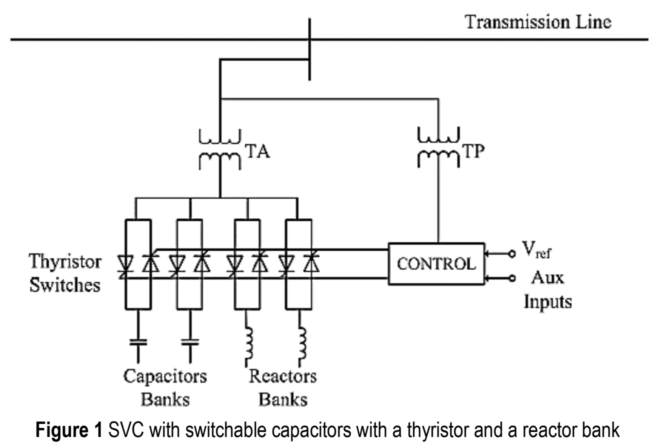

Figure 1 SVC with switchable capacitors with a thyristor and a reactor bank controlled by using a thyristor

2.2 TCSC (Thyristor Controlled Series Capacitor)

Placed in a series inside a circuit, this element offers numerous benefits for the power system. An overall schematic view of TCSC is shown in Fig. (2).

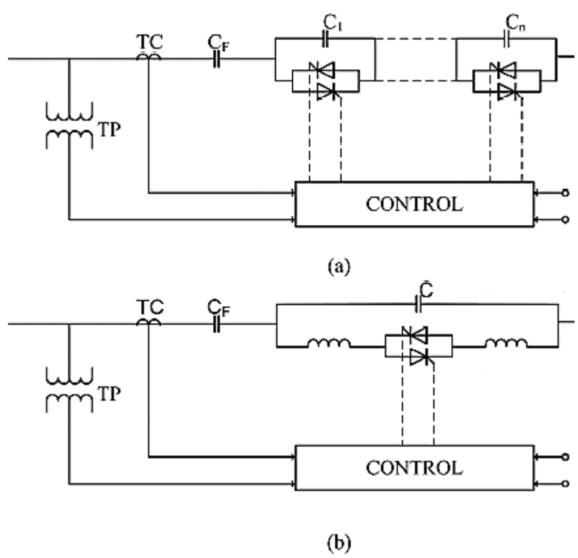

Figure 2 a) TCSC using capacitors controlled via a thyristor
b) TCSC using a capacitor parallel to the reactor controlled via a thyristor

In the first case, the compensator control in series is done separately through increasing or decreasing the number of connected capacitor banks; while in the second case, control is carried out continuously by changing the thyristor's conduction time and as a result, the reactor flow. It is worth pointing out that a combination of models A and B offers better control and more flexibility [6].

2.3 UPFC (Unified Power Flow Controller)

There are two different type of the UPFC element; coupled model and decoupled model [7].

In the coupled model, UPFC is modeled through a serial connection with a voltage source and impedance on transmission line. In the coupled model, the Jacobian matrix should be formed which becomes much more complicated compared to the decoupled model. In the decoupled model (Fig. 3), the common load-flow algorithms can be implemented easily with no need for complex Jacobian matrices.

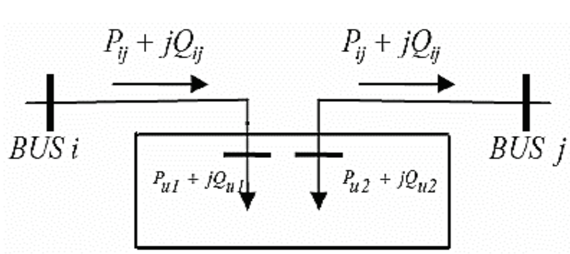

Figure 3 A decoupled UPFC model

3 WIND FARMS

Wind is a type of energy produced by the movement of air due to the heat produced by sunlight. According to meteorologists, almost 1% of the sun's energy is converted to wind. Every day, 0.1% of the wind's energy is converted into energy by humans; it means that only 0.01% of the sun's energy is used. A wind turbine is a device that converts the wind's energy into electric energy. A wind farm involves using a number of turbines together, which is cost-effective due to increased production capacity. Wind farms are modelled with respect to wind speed and the type of turbine. The wind speed model can be obtained through a variety of means such as using previous data on the time series of the distribution coefficient or Rayleigh's model usage [8]. The direction of the output power wind turbine model is also important, as it would be proportionate to the wind speed, with a non-linear relation between them.

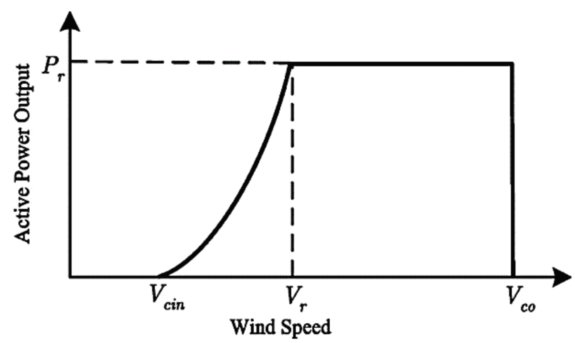

Figure 4 Power characteristic curve based on the speed of the wind turbine

The mathematical relation for the turbine's power based on speed can be obtained by using the following:

Eq. (1) shows the turbine's output power. Coefficients A, B, and C are determined by using turbine parameters.

$$P_{\mathrm{w}} = \begin{cases} 0 & x < V_{\mathrm{cin}} \\ P_{\mathrm{r}}(A + Bx + Cx^2) & V_{\mathrm{cin}} \le x < V_{\mathrm{r}} \\ P_{\mathrm{r}} & V_{\mathrm{r}} \le x < V_{\mathrm{co}} \\ 0 & x \ge V_{\mathrm{co}} \end{cases} \tag{1}$$

4 OBJECTIVE FUNCTION

In order to obtain the objective function, the system parameters intended for optimization should be first selected. In this study, the parameters including cost minimization, increasing voltage sustainability and voltage profile are taken into account [6].

4.1 Production Cost

Production cost is expressed by using Eq. (2).

$$Cost\, P_{\mathrm{G}} = ap^2 + bp + c \tag{2}$$

In these relations, a, b, and c are determined according to the type of production unit and its specifications.

The total cost is expressed in Eq. (3) as the sum of each of the unit's costs.

$$Cost\ P_{\mathrm{G}}\,(Total) = \sum_{i=1}^{N} Cost\ P_{\mathrm{G}}\,(i) \tag{3}$$

4.2 Loss Cost

To obtain the cost of losses, first the cost of a 1 MW loss is calculated and then multiplied by the number of losses according to the MW.

$$Cost\ loss^{(Total)} = Cost\ loss^{(1\ \mathrm{MW})} \cdot P_{Loss} \tag{4}$$

4.3 Pollution Cost

A modern man is faced with many challenges, such as global warming and CO_2 emissions. Consequently, efforts in line with reducing environmental pollutions and CO_2 absorption are of paramount importance [7].

$$F_{\mathrm{CO_2}}\,(Heat) = \xi P_{\mathrm{G}} \Delta t \partial K_{\mathrm{CO_2}} C_{\mathrm{p}} \tag{5}$$

Posed as a penalty for air pollution, Eq. (5) is the penalty imposed on production units according to the extent of CO_2 emission and air pollution within the Δt time interval. In this relation, P_{G} is the output of the total production of units during the Δt time interval. ξ is the standard Carbon component. K_{CO2} is the CO_2 oxygenation efficiency and C_{P} is the penalty factor related to Carbon emissions.

The sum of the total pollution costs of units is based on the Eq. (6).

$$Cost_{\mathrm{CO_2}}^{(Total)} = \sum_{i=1}^{M} F_{\mathrm{CO_2}}^{(i)} \tag{6}$$

4.4 Total System Cost

The total system cost is obtained by using the Eq. (7) which should be expressed per unit in the final function.

$$Cost\ T = Cost\ PG + Cost\ Loss + Cost\ \mathrm{CO_2} \tag{7}$$

4.5 Voltage Sustainability

The lambda parameter is used to examine voltage sustainability in the objective function. Voltage sustainability involves the voltage collapse threshold. In order to obtain voltage sustainability, the network's consumption power voltage is increased via the known coefficients until reaching the collapse threshold. The obtained point indicates the system's voltage collapse onset.

4.6 Voltage Profile of Buses

To calculate this parameter, the voltage for each bus is calculated per unit and then compared with its nominal value; then, its absolute value is calculated in all buses. Finally, the IVP (Indication of Voltage Profile) is obtained through the sum of all parameter values [9].

$$IVP = \sum_{i=1}^{N} \left|1 - V_i\right| \tag{8}$$

4.7 Fitness Function

The fitness function is formed according to the intended objectives.

$$\begin{aligned} &Fitness\ Function = a_1 \cdot Cost\ P_{\mathrm{G}}^{(Total)} + \\ &+ a_2 \cdot Cost\ Loss^{(Total)} + a_3 \cdot Cost_{\mathrm{CO_2}}^{(Total)} + \\ &+ a_4 \cdot \varphi \cdot \frac{1}{Lambda} + a_5 \cdot IVP \end{aligned} \tag{9}$$

Weight coefficients including a_1, a_2, a_3, a_4, and a_5 are specified per each objective. The objective here is to minimize the fitness function.

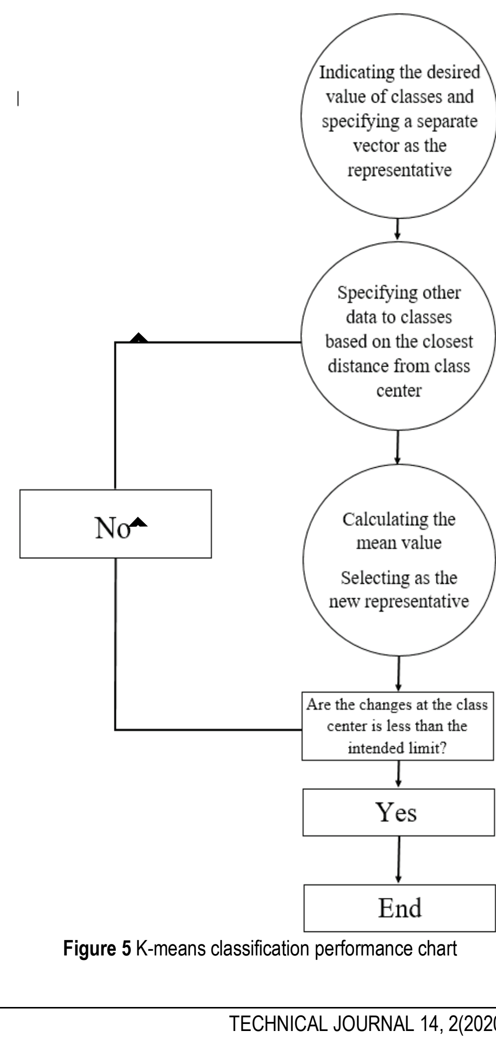

Figure 5 K-means classification performance chart

Minimizing the fitness function results in the minimization of costs and voltage profile; yet, since the intention here is to also maximize voltage sustainability, then a reversed voltage sustainability is considered in the fitness function; accordingly, a minimization of $1/Lambda$ results in an increase in lambda, i.e. voltage sustainability.

5 K-MEANS CLASSIFICATION ALGORITHM

The data of the present study include wind shifts and winds during all hours in a year, amounting to 8760 data (365 × 24 = 8760). Such number of data would add to the calculation volume. The K-means classification algorithm is used to reduce the data volume. To this end, the first ***K*** vector is selected as the representative; then, other data are classified based on the least distance from the center of classes. Next, the mean value is calculated and then selected as the new representative. When the changes at the center of the class are less than the intended limit, the classification process is finished. Otherwise, data are classified once more based on the least distance [10]. Fig. 5 shows the performance chart of the K-means classification.

6 SYSTEM DATA

Estimations are carried out based on the system data which include wind shifts and winds, both involving the consequential, random nature. In this study, a reliable regimen with respect to the consumption load and wind speed is obtained according to the pattern of previous years which can be seen in Tabs. (1), (2), and (3) and Fig. (6).

Table 1 Peak load percentage in each week of the year compared to the annual peak load

Week	Peak load	Week	Peak load
1	86.2	27	75.5
2	90.0	28	81.6
3	87.8	29	80.1
4	83.4	30	88.0
5	88.0	31	82.2
6	84.0	32	77.6
7	83.2	33	80.0
8	80.6	34	72.9
9	74.0	35	72.6
10	73.7	36	70.5
11	71.5	37	78.0
12	72.7	38	69.7
13	70.4	39	72.4
14	75.0	40	72.4
15	72.1	41	74.3
16	80.0	42	74.4
17	85.4	43	80.0
18	83.7	44	88.1
19	87.0	45	88.5
20	88.0	46	80.9
21	85.6	47	94.0
22	81.1	48	89.0
23	90.0	49	94.2
24	88.7	50	97.0
25	89.6	51	100.0
26	86.1	52	85.2

Table 2 Daily peak load percentage compared to the weekly peak load

Days	Peak load
Saturday	77
Sunday	75
Monday	92
Tuesday	100
Wednesday	98
Thursday	96
Friday	94

Table 3 Hourly peak load percentage compared to the daily peak load

Hour	Week of Winter		Summer		Spring/Autumn	
	Normal day	Holiday	Normal day	Holiday	Normal day	Holiday
12 - 1 am	67	78	64	74	63	75
1 - 2	63	72	60	70	62	73
2 - 3	60	68	58	66	60	69
3 - 4	53	66	56	65	56	66
4 - 5	53	64	56	64	59	65
5 - 6	60	65	58	62	65	65
6 - 7	74	66	64	62	72	68
7 - 8	86	70	76	66	85	74
8 - 9	95	80	87	81	95	83
9 - 10	96	88	95	86	99	89
10 - 11	96	90	99	91	100	92
11 - Noon	95	91	100	93	99	94
Noon – 1 pm	95	90	99	93	93	91
1 - 2	95	88	100	92	92	90
2 - 3	93	87	100	91	90	90
3 - 4	94	87	97	91	88	86
4 - 5	99	91	96	92	90	85
5 - 6	100	100	96	94	92	88
6 - 7	100	99	93	95	96	92
7 - 8	96	97	92	95	98	100
8 - 9	91	94	92	100	96	97
9 - 10	83	92	93	96	90	95
10 - 11	73	87	87	87	80	90
11 - 12	63	81	81	72	70	85

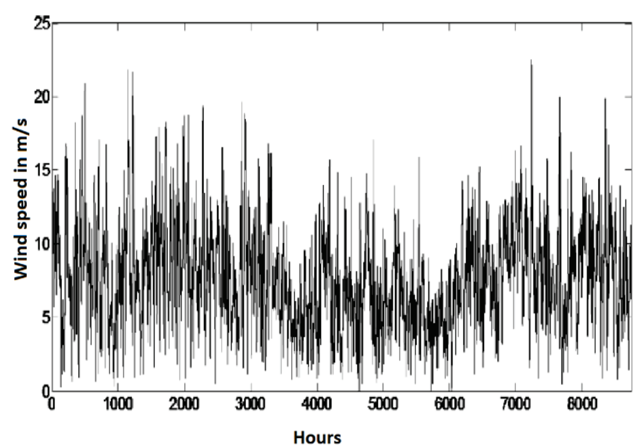

Figure 6 Wind speed model

6.1 Classification Data via the Algorithm

As it has previously been mentioned, there are 8760 data in this study intended for classification using the K-means. 8760 data are classified into 5 classes with specified class centers using the algorithm. It was assumed that the classes specified by the K-means algorithm were suitable representatives for other data, expressing the behavior of the entire data.

Table 4 double data bunch by the K-Means algorithm

Centre of group 1	(109.56, 1472.88)
Centre of group 2	(185.56, 1777.545)
Centre of group 3	(77.84, 2077.08)
Centre of group 4	(21.1, 1379.4)
Centre of group 5	(11.12, 2078.79)

6.2 Honey-Bee Mating Evolutionary Algorithm

One of the evolutionary algorithms is derived from the particular behavior of honey bees when mating. This algorithm was inspired by the special dance between the queen and male honey bees. The algorithm includes the queen, male bee, worker bee and newborns. The queen is the superior response while workers are search functions and newborns are experimental responses; worker bees are responsible for developing the newborn generation. If newborns are developed (experimental response), their superiority over the queen (the superior response) is replaced [12, 13].

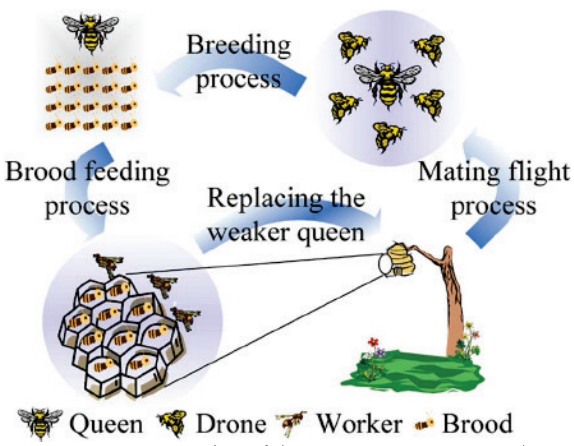

Figure 7 Modelling of HBMO (honey-bee mating optimization)

7 THE SYSTEM UNDER EXAMINATION

The system including 24-bus standard IEEE 38 transmission lines with an annual peak load of 2850 MW and maximum capacity of 3405 MW were installed in 17 buses of a wind farm system with a capacity of 200 MW which involves 100 turbines over 2 MW. The turbines' low and high cut-off speed and the nominal speed are 4 m/s (V_{cin}), 22 m/s (V_{co}), and 10 m/s (V_r), respectively.

7.1 Placement and Quantitating of SVC

When placing the SVC in 3-bus and producing a 100 MVAR Reactive Power, the fitness function will be minimized.

With an initial population of 30, the HBMO evolutionary algorithm reaches its minimum value at 0.933 per unit after 4 repetitions.

7.2 Placement and Quantitating of TCSC

In the bus 22 and the -52/63 MVAR Reactive Power, the fitness function falls to a minimum.

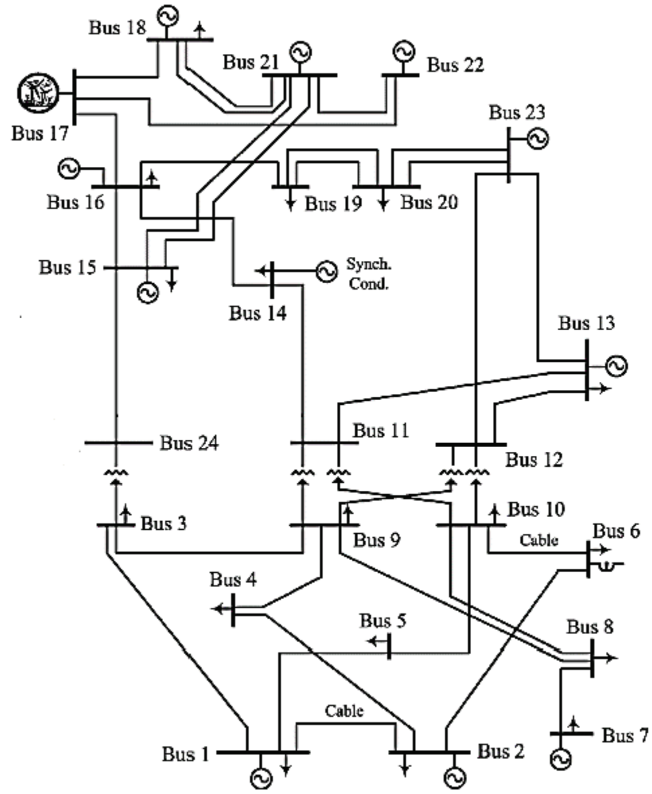

Figure 8 IEEE 24 buses

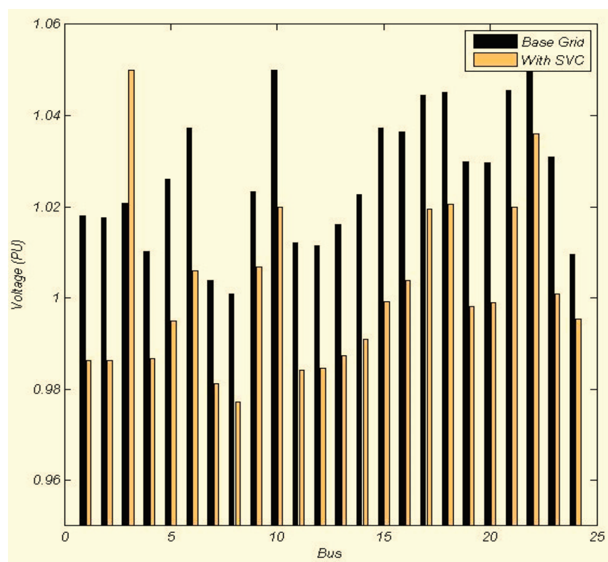

Figure 9 Bar chart on the voltage of buses in a IEEE 24-bus test network

Following 7 repetitions of the population of 30, the fitness function is reduced to its minimum number of 0.936 per unit.

7.3 Placement and Quantitating of UPFC

The fitness function is minimized in bus 17 and the reactive power of -70 MVAR (consumed reactive power).

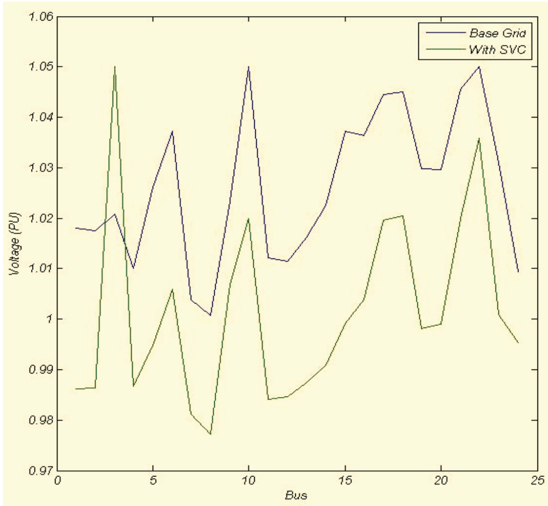

Figure 10 Continuous chart on the voltage of buses in a IEEE 24-bus test network

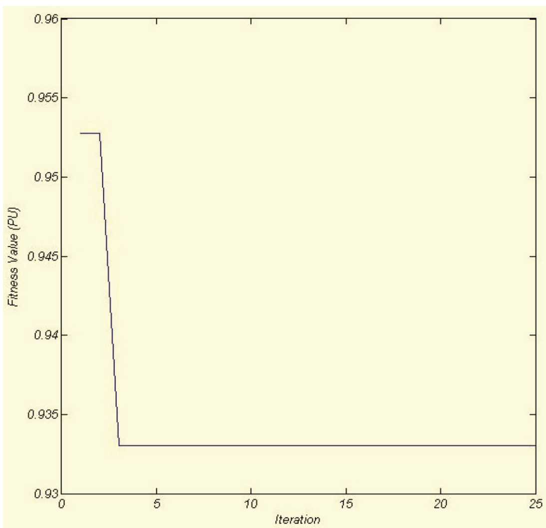

Figure 11 Fitness function chart according to the number of repetitions

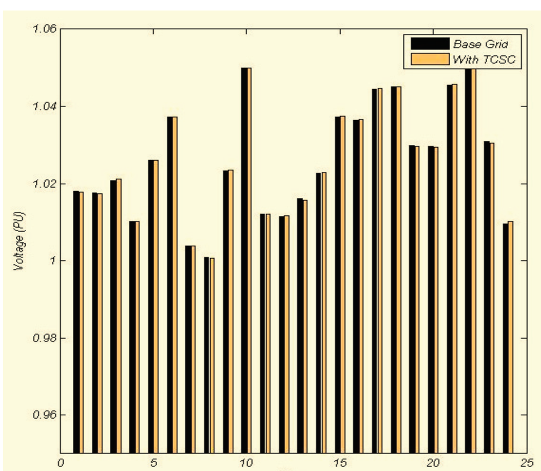

Figure 12 Bar chart on the voltage of buses in a IEEE 24-bus test network

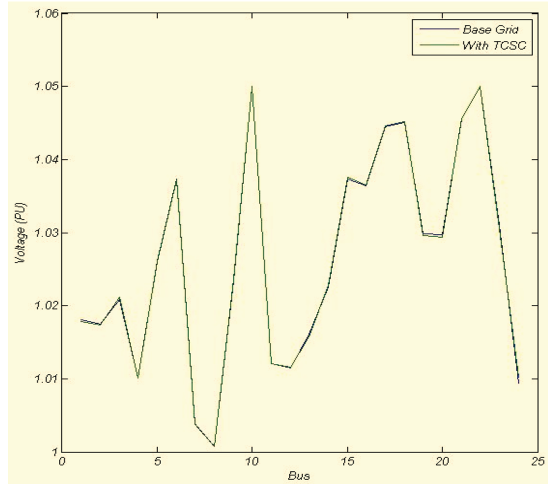

Figure 13 Continuous chart on the voltage of buses in a IEEE 24-bus test network

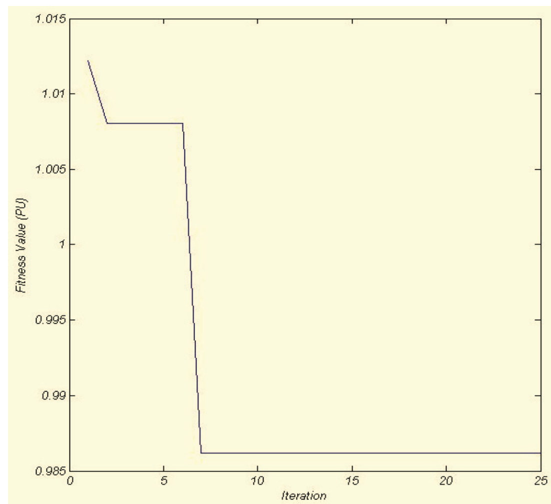

Figure 14 Fitness function chart based on the number of repetitions

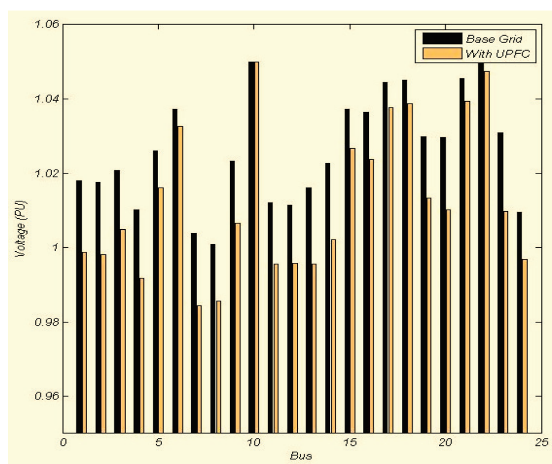

Figure 15 Bar chart on the voltage of buses in a IEEE 24-bus test network

Following 4 repetitions of the initial population of 30, the fitness function reaches its minimum number of 0.942 per unit.

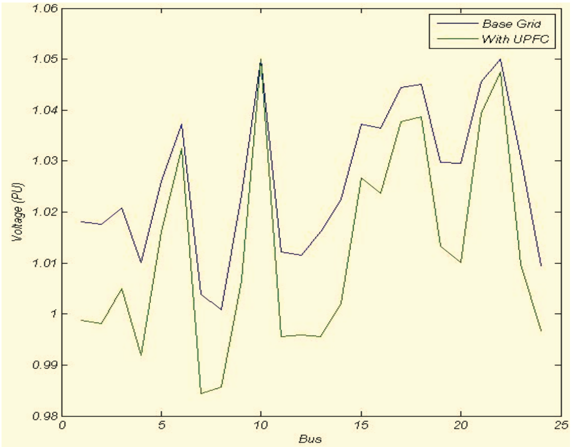

Figure 16 Continuous chart on the voltage of buses in a IEEE 24-bus test network

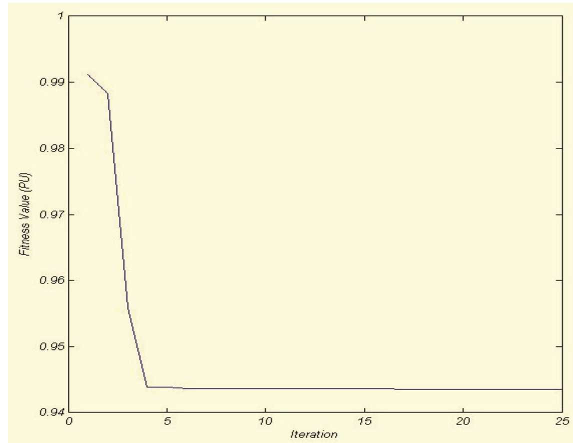

Figure 17 Fitness function chart based on the number of repetitions

Table 5 Comparison between parameter changes when applying different FACTS devices compared to the base mode.

Case	Cluster	Lambda	IVP	Cost_CO 2 1.0e+004 *	Cost_L 1.0e+003 *	Cost_T 1.0e+005 *	Cost_ Facts
Base	1	1.2437	0.5431	4.1905	1.9988	0.8406	----
	2	1.3389	0.6652	4.9299	3.5377	0.9409	----
	3	1.2849	0.7322	6.2084	5.0168	1.1184	----
	4	1.1754	0.4860	4.1656	1.6763	0.8345	----
	5	1.2843	0.7395	6.4098	4.8207	1.1458	----
	mean	1.2655	0.9332	5.1808	3.4100	0.97606	----
SVC	1	1.2993	0.3852	4.1967	2.2024	0.9976	1013.7042
	2	1.5530	0.4045	4.9372	3.7783	1.0874	998.5123
	3	1.5994	0.5265	6.2142	5.2072	1.2381	1001.4415
	4	1.2160	0.4388	4.1713	1.8646	0.9917	991.3891
	5	1.5988	0.5113	6.4157	5.0175	1.2589	989.1147
	mean	1.4533	0.4532	5.1870	6.6140	1.1147	998.83236
TCSC	1	1.6930	0.5402	4.1910	2.0126	0.8970	173.1322
	2	1.5898	0.6685	4.9307	3.5642	0.9865	180.7538
	3	1.4329	0.7332	6.2099	5.0673	1.1384	193.7340
	4	1.7086	0.4812	4.1659	1.6868	0.8912	170.8361
	5	1.4319	0.7394	6.4114	4.8749	1.1592	195.4379
	mean	1.5712	0.6325	5.1818	3.4412	1.0144	182.7788
UPFC	1	1.2695	0.3789	4.1951	2.1485	0.8991	211.0130
	2	1.3693	0.4908	4.9344	3.6863	0.9884	202.1254
	3	1.3231	0.5497	6.2122	5.1433	1.1396	219.3256
	4	1.1999	0.3452	4.1700	1.8225	0.8934	201.9658
	5	1.3226	0.5560	6.4136	4.9479	1.1604	200.0556
	mean	1.2969	0.4641	5.1851	3.5497	1.0162	206.89706

8 CONCLUSION

The entire values of examined parameters at the base mode, SVC, TSCS, and UPFC are listed in Tab. 4. Given the Lambda or sustainability, the number of values in the base mode was 1.2655, which was increased to 1.4533, 1.5712, and 1.2969 after using SVC, TCSC, and UPFC, respectively. Figures show that the TCSC mode involved a better performance in enhancing voltage sustainability compared to the two previous modes. As it can be seen in Tab. 5 regarding the voltage profile (IVP), the value at the base mode was 0.9332 which was increased to 0.4532, 0.6325, and 0.4641 after using SVC, TCSC, and UPFC, respectively. Figures show that the SVC element had a better performance in line with enhancing the voltage profile parameter compared to the other two elements. It should be noted that the weight coefficients considered in the fitness function are a_1, a_2, a_3, a_4, and a_5. Considering the importance of the voltage profile and sustainability, their coefficients include higher values compared to those of cost coefficients. Consequently, when using FACTS devices, a more suitable and more tangible performance was observed with respect to the enhancement of these two parameters, while the performance was more insignificant regarding the costs. Another important point to mention is the cost of the FACTS devices themselves, which will definitely affect the total cost. The costs of each FACTS device are listed in the last row of the table. As a result, using Facts devices leads to improved system parameters such as sustainability and the voltage profile (IVP) and pollution. Depending on each of the Facts devices and the cost and plan that we have for the system, we can choose the best Facts devices.

The objectives set in the present study regarding system parameters were achieved. A number of studies can be conducted through increasing the power of the wind farm or by using multiple wind farms in the examined system. Furthermore, the use of other FACTS devices such as STATCOM would yield interesting results. Additionally, simultaneous use of several FACTS devices in the system and the examination of results can be of great help to the operators when choosing the correct mode.

Nomenclature

P_w	Active power output, kW
V_{cin}	Cut-in speed, m/s
V_r	Rated speed, m/s
V_{co}	Cut-out speed, m/s
P_r	Rated power, kW
P_G	Production units
Δt	Time interval, sec
ξ	Standard Carbon component
K_{CO2}	CO_2 oxygenation efficiency
C_P	Penalty factor related to Carbon emissions.
F_{CO2}	Penalty for air pollution
IVP	Indication of Voltage Profile
Lambda	Voltage Sustainability

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Original scientific paper

Support of Decision in Buildings Refurbishment with a Change of Utility

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Abstract: Construction objects, including buildings, are characterized by a long period of use resulting from the properties of structural and material solutions properly designed, constructed and operated. Practice shows that functional aging of buildings is faster than technical. Therefore, for these reasons and taking into account current socio-economic concepts (sustainable development, preservation of cultural heritage, economic, location reasons, etc.) buildings that have ceased to perform their current function are subject to renovation and / or refurbishment, enabling them to perform new functions compatible with social needs: public and commercial. The choice of new functions cannot be accidental. The decision-making process regarding the refurbishment of a building with a change of utility function is subject to high economic risk, which is why it should be carried out using a methodology that ensures a holistic approach. The paper proposes a methodology of functional and functional programming in the pre-investment phase of project preparation using multi-criteria analysis of the utility function selection. The methodology is illustrated by an example of the choice of function in the adaptation of a post-production building from public resources.

Keywords: change of utility; multi-criteria analysis; refurbishment

1 INTRODUCTION

In public resources of real estate objects are being the old historic building structures or buildings under conservation protection. They are both residential and post-production buildings. From a technical point of view, they are in good technical condition or require repairs, but they no longer meet the original utility functions assumed at the time of their creation. Although they are, however, quite often in a state of degradation, their value as a cultural monument, historical or testimony of the then technique including construction, etc. is significant and worth preserving as an element of national heritage.

The choice of new utility functions in the programming process of an investment project, which is an adaptation of a building structure, usually combined with renovation and refurbishment works, is conditioned by many assumptions, restrictions - factors (technical, economic, social, environmental, etc.) and is a difficult interdisciplinary decision problem for the owner, investor and other participants in the project. In the case of public building resources, there is an opportunity when choosing to change the utility functions to consider those that provide increasing social needs whose satisfaction is statutorily supported by state administrative units (e.g. municipalities). The selection of new utility functions requires consideration of many factors and conditions, as well as many possibilities and presentation of variant solutions assessed using multi-criteria analysis [17-19].

The example presented in the article draws attention to two issues: functional aging of buildings from public resources (local government units or the State Treasury) and their adaptation to new functions ensuring the satisfaction of social needs, which is possible thanks to public co-financing. The utility function is selected in the pre-investment phase. The proposed methodology for defining the functional and utility modernization program promotes variant solutions and decisions supported by multi-criteria analysis.

2 DECISION SUPPORT IN THE PROGRAMMING AND DESIGN PHASE OF BUILDING REFURBISHMENT

Many important decisions are made in the planning process of building modernization with a change in utility function. Therefore, a holistic approach is needed, taking into account many aspects and requiring comprehensive knowledge related to the implementation of construction projects. In addition, it must be remembered that the economic efficiency of decisions taken at the building operation stage, in contrast to the preparatory phase of a new construction investment, is associated with high modernization costs. Managers and designers must face technical, economic and social challenges.

The project involving the modernization of the building with a change in the utility function requires carrying out all the actions that are required by applicable legal regulations regarding human activities in society in conducting business activities and related to the implementation of construction works [1]. Some projects require, apart from typical procedures (due to their specificity, e.g. historic buildings), additional activities.

Therefore, in the presented case study the following methodology was proposed:

I. Decision of modernization of the building, based on analysis of all conditions and restrictions, including technical condition, legal status (e.g. ownership, historic) regarding the selected object to be modernized. Initial technical research, query and analysis of archival materials.
II. Research related to the change of the utility function of the modernized facility: construction market research, surveying of social needs in the area of utility preferences, obtaining expert opinions.
III. Development of suggestions for building adaptation options for new functions.
IV. Ranking of solution variants based on multi-criteria analysis of the presented adaptation options, including

life cycle costs and economic efficiency of the investment.

V. Defining the functional and utility program. Development of a feasibility study or business plan with SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis to his final assessment.

VI. Decision to adapt the building to the selected utility function or withdraw from the decision.

The first four stages in the adopted methodology lead to the definition of a functional and utility variant program, and then its selection. While the selection is the basis for the preparation of technical documentation and implementation of subsequent stages of the project.

The presented scheme of conduct does not list exactly all stages and actions as well as making other important decisions in relation to the partial goals that make up the achievement of the goal of a given construction project. However, attention is paid primarily to making decisions based on the analysis of variant solutions of a given task (goal) and choosing the best one for given conditions (taking into account many necessary criteria), with an analysis of future scenarios of the effects of decisions made. In the investment process, the best efficiency is achieved by the right decisions in the pre-investment phase, and then project changes have the lowest costs at this stage.

It should be added that there are feedbacks between the mentioned stages of decision making, which require consideration of additional conditions and actions (e.g. extension of tests on the technical condition of the modernized building or reuse variants).

Public administration (state, local government units) are obliged to help and develop society, to meet social needs, including such as looking after children, the elderly, or providing cultural centers [2, 3]. There are many needs and public funds are limited. Therefore, decisions regarding the choice of what needs and how to meet them, and what financial resources will be needed for the investment, is an extremely important decision.

Further in the paper, in the presented case study, research and their results will be presented, which are an example of the decision-making process of choosing a new utility function of a historic post-production building implemented from public resources.

3 CASE STUDY

3.1 Description of the Building to be Adapted

The development of an example multi-criteria analysis for the selection of a new utility function required the possession of the largest possible amount of real data, including the assessment of the technical condition of the building. Therefore, the process of choosing the utility function of the post-production building was illustrated based on the building of the former card factory, which was adapted for commercial purposes in 2019.

The analyzed building, built in 1921-1923 and used as a card factory, is located in the city center and is under conservation protection [4]. It is a six-storey, without a basement building, consisting of two dilated parts, of reinforced concrete frame structure with beam ceilings (Fig. 1 and 2).

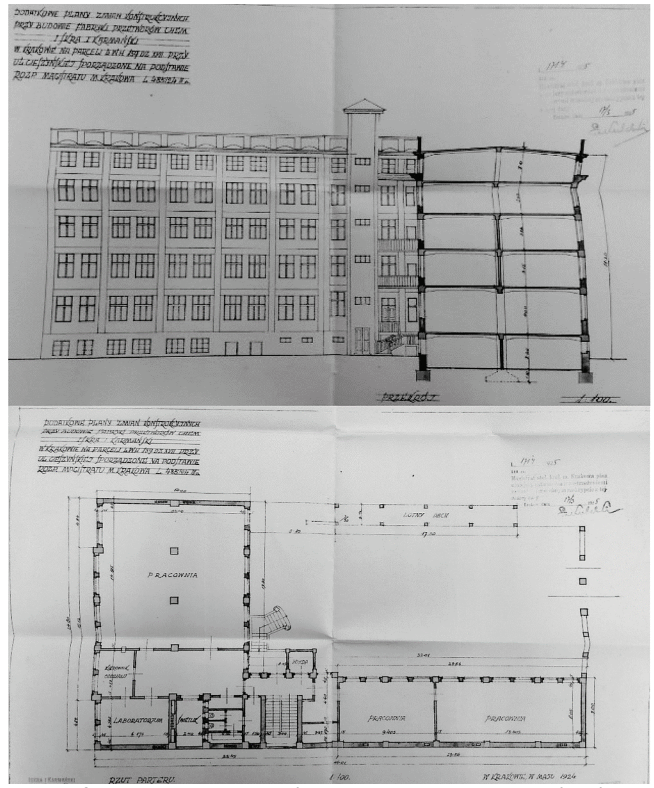

Figure 1 Sample technical drawings from the archival documentation of the factory building, Cracow, May 1924 [5]

The skeleton was filled with a brick wall 45 cm thick. The building was rebuilt several times. Figure 2 presented the appearance of the object before the renovation.

Figure 2 View of the north facade of the Card Factory in Cracow before the renovation [6]

In 2014, by decision of the Department of Culture and National Heritage, the building conditions were agreed, allowing the adaptation of the existing building for new development purposes. In June 2015, an expert opinion was made on the technical condition of the building structure, on the basis of which the necessary renovation works were established to restore the proper technical and aesthetic condition of the building and its safe use [7]. Permission was also given for the demolition of a part of the existing post-industrial building located deep inside the plot and the complete demolition of the remaining outbuilding. In sketch of the plot development of the modernized object and its designed dimensions as well as building visualization, made for the purpose of calculating the cost of adapting the building (Fig. 3).

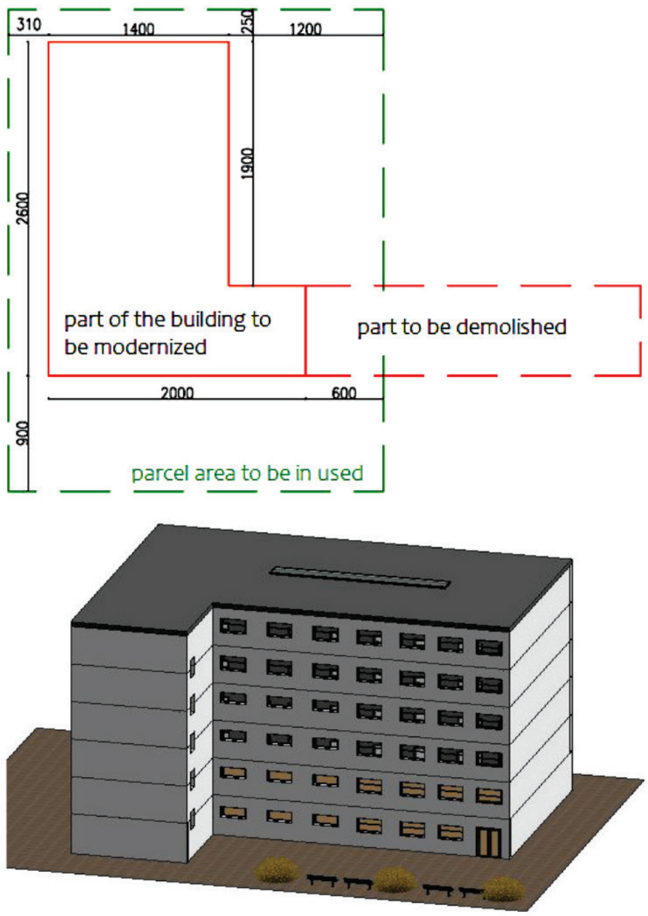

Figure 3 The modernized object and its designed dimensions as well as building visualization

3.2 The Results of Research on the Change of Use of the Building

Research on the selection of a new function of the analyzed building were included analysis of location and technical conditions (in terms of technical condition and technical possibilities of modernization and adaptation), expert opinions, and the opportunity to meet social needs and preferences. The latter mentioned aspect was examined on the basis of surveys using an online survey [8]. Factors that users value most during the operation of the facility were also identified. W The survey involved 100 respondents, including 90 people up to 30 years old, 7 respondents aged 31 to 50 years and 3 people over 51 years old. Interesting results of this research, characteristic of the majority of young respondents, are presented in Fig. 4. "Other" items include: library, garden and gallery, reading room, shopping and service building, community center, museum, school. The study participant had to choose up to three utility functions of the building from among those proposed in the survey. The most frequently indicated were: flats (49%), gym (34%), nursery/kindergarten (29%), library (25%) and offices (24%).

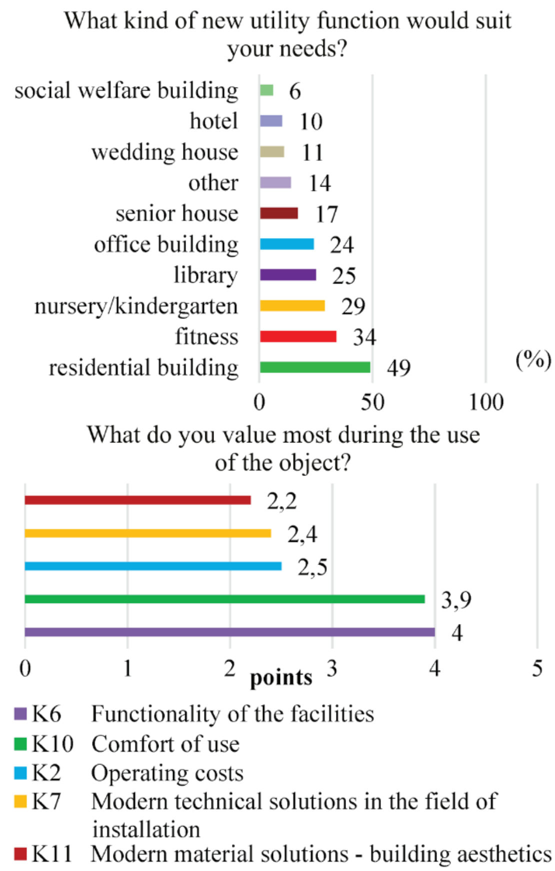

Figure 4 Survey results [8]

In the opinion of other participants of the construction market, such as developers, investors, contractors of construction works, there is a high demand (in modernized buildings) for apartments, service and office premises, including rent. The demand also concerns nurseries and kindergartens, as well as nursing homes (retirement homes) for the elderly and, e.g. senior clubs, because of the aging of the population. In 2018, in Poland the percentage of ∈people aged 60 and over is 24.4% of the total population, including 8.3% people more than 85 years old [9].

Considering the results of the survey, it was decided to consider two variants of adaptation with multi-use functions. **The first** - kindergarten and nursery (max 120 children) on the lower floors and a library with a reading room on the upper floors, the ground floor will be designated as a service premises - a restaurant. **The second variant**: on the ground floor and first floor - a community center and a senior's house (max 62 people) on the other floors.

3.3 Technical Characteristics of Both Variants - Scope of Renovation and Modernization

Given the technical condition of the building from the point of view of modernization, regardless of the type of future use, the building requires many renovation works, indicated in the technical expertise [7]. Those are:

- demolition of the slab between the ground floor and first floor and its re-construction, higher than the existing slab, due to the need to increase the usable height of the lower floor and which will allow obtaining the same heights on each floor. The height in the storey will be from 2.9 - 3.1 m. The slab will be made in furrows in existing masonry walls, and on reinforced concrete elements joined with reinforced concrete columns.
- reconstruction of the communication shaft, including reconstruction of the staircase and incorporation of the elevator shaft,
- reinforcement of slabs,
- strengthening the foundations.

Other construction works included in the sample analysis are result from the adopted utility functions for two variants. Construction and material solutions in both variants are similar.

The estimated cost of adaptation for I variant is 682 245 EUR, and in II – 1 544 512 EUR.

3.4 Multi-Criteria Analysis of the Assessment of the Proposed Building Adaptation Solutions

The proposed variants of changing the utility function of the analyzed building were subjected to multi-criteria analysis using two classic methods commonly known and described in the literature: synthetic indicators [10] (from the group of taxonomic methods [20, 21]) and AHP (Analytical Hierarchy Process) [11, 22, 23, 24]. The set of proposed evaluation criteria is: K_1 - cost of renovation and modernization, K_2 - operating costs, K_3 - life cycle costs, K_4 - NPV (assessment of investment efficiency) , K_5 - labor consumption, K_6 - surface division functionality, K_7 - modern technical solutions for installation, K_8 - nuisance of repairs for future users, K_9 - social need, K_{10} - comfort of use, K_{11}- modern material solution –building aesthetic.

Five out of eleven evaluation criteria were selected, based on the opinions of survey respondents, experts and those interested in the investment. Their mutual relations were taken into account in the selection of criteria. Weights of criteria in both methods of multi-criteria analysis were adopted according to the AHP method.

Particular attention was paid to the cost analysis. The (K_2) criterion for the costs of building operating and the investment effectiveness determined by means of the NPVs (Net Present Value) [8] were taken into account, considering the period of 30 years of operation. In relation to the current approach to investment assessments, the total life cycle costs (K_3), consisting of the costs of purchase, ownership and disposal of the building, were also determined [25]. The conducted cost assessment does not take into account the cost of disposal (demolition of building is not expected).

The cost calculation includes funding for kindergartens and nurseries, care for seniors, libraries and community centers by municipalities and required by law. The following assumptions were made in the calculations:

1. Subsidies for kindergartens [12] are calculated in accordance with Article 12 of the Act of 27 October 2017 on financing educational tasks [2]. In connection with the above, every year the commune receives a subsidy for pre-school education. In 2018, funding for the public kindergarten was 167 EUR / per child/ per month. For the purposes of calculating the cash flow for option I, the following were adopted:
   The daily cost of maintaining a child in kindergarten is ~ 4 EUR, assuming full board and additional hours for which the parent pays - the monthly cost is about 78 EUR. Co-financing from the commune for one child was founded 155 EUR per month.
2. Staying in the senior's home is paid and in accordance with art. 59 of the Act on social assistance [3], it is the commune body that decides about the costs of stay [13]. Act in art. 61 presents a list of persons who bear the costs of living a pensioner, showing who the payment obligation is transferred to. These are, in order: the inmate, spouse (s), descendants, ascending relatives, and commune.

A resident can pay a maximum of 70% of their income for their stay. The municipality, on the other hand, finances the difference between the average cost of living in a senior's home and the fees paid by the abovementioned persons [14]. For the purposes of article, the following was assumed: daily cost of staying in a senior's home – 20 EUR, including full board, medical care, rehabilitation, etc. - monthly – 600 EUR. The income of the resident was assumed at the amount of 556 EUR and a monthly fee for his stay of 378 EUR, the remaining difference, i.e. 222 EUR, is paid by the commune.

Despite the income from the rental of service premises designed on the ground floor, NPV (Net Present Value) for both variants are less than zero (therefore investments are unprofitable, from the point of view of the investor, which is e.g. a commune). Annual cash flow is negative. Such NPV was predictable, however, this criterion was included in the assessment for comparative purposes, it is destimulant.

After selecting the criteria, determining their values and weights, global calculations of the proposed variants of the new form of use of the building began. Due to the subjective nature of multi-criteria analysis methods, two methods were used that did not require complicated calculations. The AHP method is well described in the literature and very popular [11]. The method of synthetic indicators consists in the construction of a scalar, whose numerical value is a synthetic assessment indicator. The study uses an additive corrected indicator J according to the formula:

$$J = \sum_{j=1}^{m} (z_{ij} \cdot w_j),$$

where: z_{ij} - a coded measure of the i^{th} variant of the j^{th} criterion, w_j - weight of the j^{th} criterion.

Coding, i.e. reducing the value of the criteria to an unnamed value, can be done using various methods. The article uses the standardization method [10, 8]. Tab. 1 shows the final calculation results and all intermediate calculations are in the [8].

Table 1 Summary of the results of multi-criteria analysis, based on [8]

Variant	Criteria values				
	K_2	K_3	K_4	K_6	K_9
	Weight w (0÷1)				
	0.31	0.42	0.06	0.04	0.17
V_1	374 444	25 939 651	−9 156 352	2	4
V_2	362 667	25 157 343	−8 955 058	4	5
Assessment result					
	Synthetic indicators		AHP – global priority		
V_1	0.141		0.346		
V_2	**0.173**		**0.651**		

K_2 - operating costs (EUR), K_3 - life cycle costs (EUR), K_4 - NPV (EUR), K_6 - surface division functionality (1-5 scale), K_9 - social need (1-5 scale)

The calculations show that under the adopted conditions and assumptions, variant 2 - connecting the community center with the senior's house received a higher rating in both the AHP method and the synthetic assessment method. The largest impact on the analysis result was the value of co-financing allocated by the commune for the given units, because in the case of kindergarten they accounted for about 60% of the total operating costs of the facility, and in the option with the senior's home, the costs of co-financing constituted about 45.6% of the operating costs. Such a difference in the scale of the year is a considerable expense for local governments, which provide subsidies for the functioning of such facilities every year.

4 SUMMARY

The buildings are characterized by a long period of existence, in good technical condition, with their proper use and maintenance. They "age" faster in functional terms. The choice of a new function, building and its adaptation and modernization is a very complex and responsible decision-making process. Requires consideration of many aspects.

In the example of decision making process presented in the article, the multi-criteria analysis method was used.

Among the many methods presented in the literature (e.g. [15, 16]), classical ones, which do not require special mathematical preparation, and with some practice - not consuming were chosen. The advantage of multi-criteria analysis is the inclusion of a holistic approach in solving problems and making decisions.

This approach is required in the pre-investment phase and the construction project preparation process. In the topic presented in the article on the selection of the utility function of buildings aging from public post-production resources, this approach is particularly recommended. The choice of function should take into account many aspects: technical, economic, social. In the case of investments financed from public funds and being part of the state's obligations in the field of social assistance, the economic efficiency factor mainly plays an informative role, although it may have a weight. Therefore, the final decision regarding the choice of adaptation of a given building should be made after the development of the functional and utility program and the feasibility study re-evaluated, e.g. using SWOT analysis. This is the last item in the proposed methodology for identifying the construction investment program.

Apart from the huge needs in terms of access to public kindergartens or senior homes, the building chosen for analysis was in fact adopted as an office building. This choice was also accurate due to its location in the city center, the needs of the real estate market and technical reasons. The structural and functional layout of the modernized building did not require significant changes, and therefore did not entail additional expenditure on its adaptation.

Notice

The paper will be presented at PBE2020 – International Scientific Conference "People, Buildings and Environment 2020". The 14th conference will be held in the Rožnov pod Radhoštěm city, the Czech Republic, from 7 to 9 October 2020. The paper will not be published anywhere else.

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Original scientific paper

Management of Business Risk Hedging in Construction Contracts from the Perspective of Public Investors

Barbara Andrlova, Jana Korytarova*

Abstract: Risk management of construction projects presented in the article focuses on the management of business risk from the perspective of public investors in public works contracts in the Czech Republic. Based on the data analysis and a comparative study of specific attributes in contracts for works, the result of the research has been a portfolio of specific instruments and their recommended parameters for effective business risk management. Qualitative analysis was conducted using a questionnaire survey and structured interviews with public sector representatives to share their views on the current practice of protecting public procurement with regard to mitigate business risk. Types, functions and recommended parameters of hedging instruments has been proposed. Effective forms of hedging are mainly liability insurance for damage to things, property and health, contractual penalties, retention money and bank guarantees. Results of the research were compared with foreign practice and international contractual standards.

Keywords: business risk management; construction project; contract for work; hedging instrument; public works contract; retention money

1 INTRODUCTION

Priority of the business environment in every developed country shall be economic stability of companies and providing safe and healthy competitive environment. Public procurement for construction works contracts forms a significant part of construction production in the Czech Republic. Current developments in the construction industry state: *"The production of civil engineering, which is mainly dependent on public funding, annually grew by 4.0%."* [1] Preparation and implementation of construction contracts brings a number of risks that may endanger the achievement of the objectives of construction projects. Therefore, it is in the interest of all stakeholders to minimize the probability of risks occurrence and to reduce the intensity of their impact.

The interaction between construction, insurance and the law stems from the activity generated by the construction process [2]. MultiStakeholder Consultative Framework for Construction Health and Safety presents the role of client and project manager and importance of their relationship [3]. Conscious acceptance of investment risks and risk allocation based on the ability to control them by the project participants is therefore a necessary precondition for achieving success in a public construction project.

The aim of this research is to gain insight into the issue of business risk management in contracts for work in construction projects. Contract risk is defined as a risk or set of risks that has the capacity to impact on a contract to the extent that it deviates from the outcome expected by either party [4]. To protect investor, contractor and other shareholder interests, all of them need to be proactive in assessing their contract risks. By taking a proactive approach to contracts, companies help mitigate contractual risks while making improvements that will enhance the business through increasing revenues or reducing costs [5]. According to [6], effective risk management typically generates positive results on a project by improving the project performance, increasing the cost-effectiveness and creating a good working relationship between contracting parties.

The intention is to verify whether the forms of hedging used and their parameters specified in the contracts are effective in practice, i.e. if they fulfil their function, and whether the choice of a suitable hedging instrument affects business risk management of the project or whether the appropriate combination of hedging instruments increases the effectiveness of the construction contracts protection. For this purpose, quantitative research and data analysis were performed on a comparative study. The findings were completed by a qualitative survey carried out among the representatives of the public sector. Comments by foreign experts in the field of construction and engineering law are also provided.

2 RESEARCH METHODOLOGY

Based on a scientific literature research about hedging in construction projects [7, 8], a quantitative research into the forms of hedging used in contracts for work in practice was proposed. Furthermore, a qualitative survey was carried out using the method of structured questionnaires and interviews with representatives of public investors in order to share their views on the issue. A comparison of the forms of hedging used on an international scale was also made.

2.1 Quantitative Research

The research set consisted of a database of selected public works contracts defined by the field of activity according to the CPV (Common Procurement Vocabulary) code list and codes 45000000-7 – Construction work and 45200000-9 – Works for complete or part construction and civil engineering work. The contract agreements were published in the phase of performance of contracts for work on the profiles of contracting authorities during the 2011–2018 period. As part of the analysis, a structured database of input values was created according to the tender documentation. As part of quantitative research, a comparative study of case studies of a selected category of civil engineering works construction was designed on the construction and reconstruction of public buildings research set, for which the public investor is responsible for financing.

Partial parts of the research were processed in successive steps (see Fig. 1).

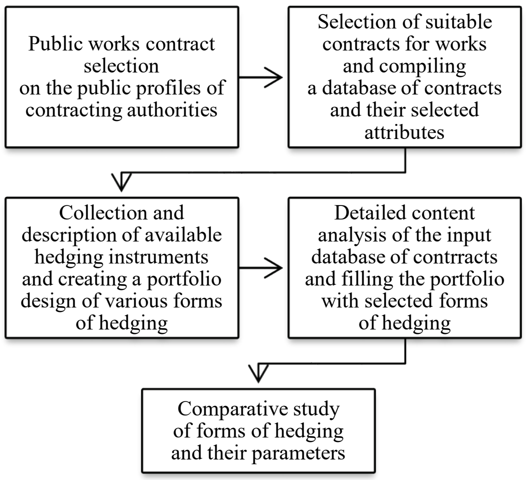

Figure 1 Methodology and procedure of quantitative research
Source: authors' own processing

Contracts for work and their amendments, i.e. publicly available documents and related information provided in procurement procedures at the stage of publishing of the final contract for work, were subject to detailed content analysis. The research set consisted of 66 contracts for work in total. The resulting conditional selection filter included two research samples – case studies:

- 35 contract agreements for construction work projects related to the building modifications of school buildings in the 2011–2016 period [9],
- 31 contract agreements for construction work projects related to the construction of homes for the elderly in the 2013–2018 period [10].

For the purpose of systematic data processing, an item structure of 28 selected attributes from the calls of public procurement was created for the input database of available forms of hedging and their parameters in real work contracts in practice, which were subsequently researched. Defined forms of hedging according to the draft of the standards of the General Terms and Conditions [11] were also used for the creation of available hedging forms database. A total of 1,675 input values were obtained from the content analysis, from which a final database of the used hedging forms and their parameters was created in the text and numerical formats in the research set of work contracts. The conclusions of the case studies research were complemented by construction work projects in the field of wastewater treatment [12] and were summarized in a comparative study, which were used to create a portfolio of effective forms of hedging, as shown in the research results.

2.2 Qualitative Research

The aim of the qualitative research was to supplement the performed data analysis with regard to the used hedging instruments in work contracts and to verify their real use in practice. Qualitative research was carried out using the method of a structured questionnaire and structures interviews. The questionnaire was compiled on the basis of the results of quantitative research and pilot-tested at the investment department of the Regional Office of the South Moravian Region. In June 2019, responsible persons from the ranks of public investors from all regional authorities in the Czech Republic were approached with a request to fill in an online questionnaire and to share their perspective from practice on the issues addressed. Data from the Central Bohemian Region, the Liberec Region, the South Moravian Region and the Capital City of Prague were obtained. To supplement the online questionnaire survey, topics for structures interviews were proposed, which were conducted with the representatives of public investors. Representatives of the regional authorities of the South Moravian and North Moravian regions, who are founders and implement investment plans in their scope (237 contributory organizations in the South Moravian Region, 221 contributory organizations in the Moravian-Silesian Region – hospitals, schools, cultural facilities, roads of class II and III etc.) were approached to share their experience.

3 RESULTS

Based on a scientific literature research, quantitative research and data analysis, a qualitative survey using structured questionnaires and interviews with investor representatives, the findings of the researched issue were summarized in a portfolio of effective forms of hedging in work contracts for the construction works. Results of the research were compared with current foreign practice and international contractual standards.

3.1 Results of Quantitative Research

Both analysis and data analysis of the research set were performed on a representative data set, which consisted in the creation of a database of contracts for work of sector-specific public procurement for construction work. The content analysis made it possible to find out and describe which sanction arrangements and hedging instruments occur in the contracts for work and with what parameters. The selection of hedging instruments and their amount have been effectively adjusted to protect both parties – the investor and the supplier – throughout the course of the whole construction project. A detailed analysis of the forms of hedging in the research set revealed that the hedging instruments used for risk management were mainly:

- Liability insurance for damage to things, property and health,
- Contractual penalties,
- Retention money,
- Bank guarantees.

The agreed forms of hedging and sanction arrangements are expected to be assigned a contractual consequence and their amount should discourage breach of the contract. From the investor's point of view, it is more efficient to have a suitable insurance for the given construction project or to keep a part of the contract price as a retention in case of non-compliance with the supplier's obligations. Common errors in contractual penalty arrangements were identified as vagueness in the specification of obligations, errors in business conditions, confusing indications for the application of contractual penalties or interest on arrears, and disproportionate amounts of penalties.

The resulting comparison of research samples showed that liability insurance for damage to things, property and health increased over time from the original 80–100% to the insurance of at least in the amount of the contract price up to twice the price of the work. Unreasonable claims can adversely affect the costs associated with acquiring insurance if they do not correspond to the actual or future value of the contract. Retention money rates of 10% occurred in one third of the cases researched.

The Bank Guarantee for the proper execution of the work (Performance Guarantee) and the Warranty Guarantee gradually replace the application of the retention. An important aspect of the comparative study appeared to be the comparison of case studies with the values of other industry-specific contracts. Therefore, a comparison of the forms of hedging in the field of wastewater treatment [12] was carried out, which states that retention was considered a traditional form of business risk management in contacts for work until 2013, later it tended to be more often replaced by a bank guarantee.

3.2 Results of Qualitative Research

The results proved the topicality of the subject and the preventive, sanction and reimbursement functions of hedging instruments were confirmed in practice. To effectively hedge contractual relations, it is necessary to individually set the optimal and effective portfolio of hedging instruments and their parameters for each public procurement, which increases the complexity of preparing the tender documentation and contract documents on the part of public investors and places increased demands on the quality of project documentation.

3.2.1 Questionnaire Survey

The aim of the questionnaire survey was to find out the most frequently used hedging instruments and to describe their use effectiveness in contracts for work to hedge business risks from the perspective of a public investor. Answers to the researched issue were obtained from representatives of four regional authorities – from the employees of public procurement departments and from the employees of the investment department.

Respondents agreed that contractual penalties, bank guarantees, retention and work insurance represent effective hedging instruments in the performance of a contractual obligation. Respondents confirmed that the interest of contractors in procurements covered from public funds results from the certainty of financial performance. However, the current situation in public procurement is complicated by the complexity of the procurement process and the lack of interest of contractors in reference contracts. The respondents told: *"There is currently lower interest from suppliers – there is not enough labour force."; "To improve the contractual relationship would help perceiving the successful implementation of the contract as a common goal of the investor and the contractor - a relationship based on mutual cooperation, risk management and timely resolution of problems."* Public investors see lack of interest on the part of contractors in the risk of negative media coverage (public opinion) in case of non-compliance with the conditions of the project, in the restrictive conditions of subsidy programmes, unfortunate interest of investors only in the cheapest offer, lack of capacity of contractors or subcontractors and the boom in the construction industry. The respondents identified difficulties that are important for the effective performance of the contractual relationship: risks of an administrative and financial character, failure to meet the work schedule and the progress of the construction contract, frequent problems with subcontractors, poor project management of the construction contract and inability to communicate successfully. According to half of the respondents, changes in the project compared to the original proposal are almost always caused by a fault in the project documentation.

3.2.2 Structured Interviews

The interviews showed that the hedging instruments are useful, however the price of the work is decisive, otherwise it discourages the contractor from signing the contract. Hedging in work contracts always includes work insurance - construction and assembly insurance and liability insurance for damage to things, property and health, contractual penalty agreements, retention and sometimes bank guarantees. Tenderers have the choice of applying for a bank guarantee or a retention, which may be required at 10-20% of the price of the work. The retention is bound to the successful course of the approval procedure, then it is released. Experience shows that companies do not want a bank guarantee. Defects during the warranty period can be claimed directly by the user of the finished construction work, in addition to the investor. Contractual penalties are agreed for each public procurement by agreement of the contracting parties.

3.3 International Comparison of Used Forms of Hedging

Abroad, the usual amount of retention money ranges from 5–10% of the contract price and there are various procedures for the maturity of the retention. In most American states, retainage *(in AmE means retention money)* is a typical practice in both public and private construction contracts and permissive nature of retainage varies from state to state. Some owners and prime contractors believe the retainage serves as a type of insurance for owners, but it can have the unfortunate effect for subcontractors to add the hidden cost of retainage to their bid offer which increases the cost to owners. Therefore some states have reduced the maximum rate of retainage permitted. In [13] is shown the Retainage Laws in the 50 States in public sector (highway work, projects of municipalities and counties, school buildings etc.). In most states retainage shall not exceed 5% of the value of the work completed by the contractor. The amount of retainage in California for public works contract payments ranges from 10% to 5%, in most cases [14].

According to [15], which covers common issues in Construction & Engineering Laws and Regulations in 32 jurisdictions, the contractual retention in England is usually 3-5% of contract price. Half of the amount is usually released at practical completion of construction project and the rest after the expiry of the liability period or after issuing a certificate under the contract.

Contractual arrangements for sanctions (contractual penalties) represent a commonly used tool for allocating risks in construction contracts. Bank guarantee for the proper execution of the work (Performance Bond) guarantee that the contractor honours his obligation and duly fulfils the terms of the contract. The guarantee serves to guarantee the date and quality of the delivery for the period between the signing of the contract and the take-over of the finished work. Another bank guarantee is a guarantee for the quality of the work during the warranty period (Warranty Bond) for the period between the take-over and termination of the supplier's liability, i.e. the expiry of the limitation period. The contractual parties can in principle agree on a percentage of guarantees. However, if the bank guarantees are specified in the general terms and conditions of the investor or in the contract, the percentage is limited according to German case law. Performance Bond can reach up to 10% of the purchase price and Warranty Bond up to 5%. These data became a standard in small and medium-sized projects. However, larger construction projects may be subject to significantly higher values. For example, in Norway, in accordance with [16] the supplier provides the investor with retention for the fulfilment of his contractual obligations during the execution period and the warranty period. Retention money during the implementation phase of the project, including liability for late completion, represents 10% of the contract price. Upon take-over/delivery of the work, the retention is reduced to 3% of the contract price for any warranty claims for a period of three years. The retention is provided in the form of a standard bank guarantee (not an on-demand guarantee) from a bank, insurance company or other financial institution. In Sweden, the rules [17] apply, which limit the bank guarantee (Performance Bond) to 10% of the contract price during the construction implementation until the approval of the final inspection/handover. The warranty in favour of the customer is reduced to 5% of the contract price during the first two years of the warranty period.

3.4 Portfolio of Effective Forms of Hedging in Public Works Contracts

It was confirmed within the research and performed data analysis that effective forms of hedging for risk management are mainly:

- Liability insurance for damage to things, property and health,
- Contractual penalties,
- Retention money,
- Bank guarantees.

The obligation to arrange insurance is included in the qualification criteria of the tender documentation for the public procurement as a fundamental part of the fulfilment of the contractual obligation. Due to the uniqueness of each project, it is appropriate to approach the insurance of each work individually [7].

Retention in the form of a financial retainment primarily serve to ensure the take-over of the construction work by the contracting authority in a completed state without defects and unfinished work and is commonly used by public investors. However, retentions can be large amounts of money and may cause cash flow problems for contractors and the supply chain or in case to recover retention money from the client, perhaps in a situation where the client has incorrectly identified something as a defect [18]. Therefore, its recommended amount is 5%, at max. 10% of the price of the work. Current practice shows that bank guarantees provide the investor with similar hedging as a retention, but offer suppliers more benefits. Commonly used bank guarantees on the financial market, their functions, parameters and recommended maturity are listed in Tab. 1.

Table 1 Types, functions, parameters and maturity of bank guarantees
Sources: authors' own processing; Klee, 2018 [19].

Type of bank guarantee	Recommended parameters	Maturity of the bank guarantee
Tender Guarantee	1–5% of the expected value	After the end of the selection procedure for the contractor
Performance Guarantee	5–10% of the contract price	After completion of the work (by the deadline for take-over the work without defects and unfinished work + 30 days)
Warranty Guarantee	5–10% of the contract price	After the warranty period expiration
Retention Guarantee	5–10% of the contract price	Upon completion of a certain phase of the project, after the deadline for defect notification
Advance Payment Guarantee	5–30% of the contract price	After the expected date of completion of the delivery of work/service

Tab. 2 summarizes the basic types of contractual penalties and their parameters according to the general business conditions for the construction completion [11] and provides a comparison with the basic types of contractual penalties and their recommended parameters according to the research results. For some types of penalties, it is proposed to consider reducing the parameters to 0.05% of the amount owed or to increase the penalty in case of error and to prevent the contractor from non-cooperating in elimination of defects and unfinished work.

The portfolio of effectively selected hedging instruments and their parameters in the work contract for a specific construction project allows the public investor to ensure and meet the material objectives of the public procurement in terms of compliance with the three imperatives – time, cost and work quality and thus help to meet the principle of 3E – economy, efficiency and effectiveness of investment construction project not only in the Czech Republic but also in contract management in the member states of the EU [21].

Table 2 Basic types of contractual penalties and their parameters - comparison of general terms and conditions for construction completion (S.I.A., 2007) and sanction arrangements parameters according to the own research
Sources: [11]; authors' own processing

Type and function of the contractual penalty	General terms and conditions for construction completion [11]	Recommended parameters for the amount of contractual penalty [own work]
For late payment with monetary performance	0.1% of the amount due for each day of delay	0.05–0.1% of the amount due for each day of delay
For failure to meet the deadline for completion of the work	0.1% from the price of the work for each started day of delay; may not exceed 10% of the price of the work	0.05–0.1% from the price of the work for each started day of delay
For failure to eliminate defects and unfinished work	*CZK* 1,000 for each piece of unfinished work or defect which is delayed and for each day of the delay	*CZK* 1,000–5,000 for each piece of unfinished work or defect which is delayed and for each day of the delay
For not clearing the construction site	*CZK* 5,000 for each day of the delay	*CZK* 1,000–5,000 for each started day of the delay
For failure to eliminate the claimed defects during the warranty period	*CZK* 1,000 for each defect which is delayed and for each day of delay; if it is a defect that prevents the proper use of the work, or if there is a risk of large-scale damage - an accident, both parties agree on a contractual penalty in the twice amount	Minimum of *CZK* 1,000 for each defect which is in delay and for each day of delay; if it is a defect that prevents the proper use of the work, or if there is a risk of large-scale damage – an accident, both parties agree on contractual penalties in the twice amount

Note: exchange rate EUR/CZK is 27.67, 15.05.2020

4 DISCUSSION

The result of the research is the design of a portfolio of hedging instruments for protection of contractual obligations against business risk so that their function for which they were determined (preventive, sanction or reimbursement) was fulfilled. In a qualitative survey using the method of a questionnaire and structured interviews, it was found out that investors carefully consider the choice of hedging instruments when establishing a contractual relationship with the contractor in order to protect a construction project with respect to business risk management. Optimal composition of hedging instruments increases the efficiency of protection of a specific construction order. It should be noted that there is a portfolio of hedging instruments, the parameters of which are defined by the rules of subsidy programmes, legal norms and decrees, which change over time and according to custom. The contracting authority must take into account the principles of 3E in any purchasing and management, which should ensure compliance with the scope and quality, fulfilment of objectives and social benefits of the public construction project. The results of the work can increase awareness of conceptual knowledge of technical, economic and legal areas and improve approaches to risk management and contract management throughout the life cycle of a construction project.

The results of this work and foreign experience show that there is no standardized procedure to replace the need for systematic risk identification and risk analysis of each specific construction project. In the preparatory phase, the client's professional ability is to set priorities for each individual construction project on the part of the public investor, which no standardized procedure would replace. The evaluation of tenders by directors of construction companies in the Czech Republic is not perceived very positively (CEEC Research, Q4/2019) and the public sector has significant room for improvement in this respect, e.g. in the responsible procedure in public procurement.

A useful tool for sharing international experience are [21] managed by the Global Legal Group from the UK, is available at https://iclg.com. For the purposes of this research, information from the field of Construction & Engineering Laws and Regulations was used, which includes key topics occurring in designing and implementation of construction projects, supervision of construction contracts, dispute resolution, etc. Statements of ICLG database professional contributors contained comments on selected forms of hedging – retention, sanction arrangements and bank guarantee in various countries.

The issue of retention money has provoked government review, for example in the United Kingdom, where economic impacts on suppliers due to retained funds are perceived in practice, affecting cash flows of the companies or being completely lost in the event of insolvency in the supply chain. Currently, the Department for Business, Energy & Industrial Strategy of the Government monitors the costs, benefits and impacts of using retention on the entire construction sector. In 2017, an extensive scientific report on Retentions in the Construction Industry [22] was prepared. The methodology of this report could be an inspiration to map the current situation of this issue in other countries.

5 CONCLUSION

The article presents the forms of business risk hedging of the construction work, which should be identified, analysed and managed within the corporate risk management, especially in the pre-investment phase and subsequently incorporated into the contract for work in the investment phase of the construction project. Effective forms of hedging are mainly liability insurance for damage to things, property and health, contractual penalties, retention money and bank guarantees. Types, functions and recommended parameters of hedging instruments has been proposed. The hedging conditions set out in the contracts for work should be proportionate and should provide a balanced allocation of risks and responsibilities between the contracting parties, then the contract will have an capacity to manage business risk mitigation.

The aim of the public investor is to ensure the economic efficiency of investment plans and to protect the investment funds spent from public sources. The agreed conditions in the contracts for work should reflect the objectives of compliance with the selection of the most suitable contractor of construction work according to the principle of economic advantage of the offer and in terms of fulfilling the principle of 3E – economy, efficiency and effectiveness, taking into account the risk management of the project. This can be achieved through the purposeful use of effective hedging throughout the life cycle of construction contracts.

Elimination of risks in well-established contractual obligations and decision-making processes in the actual implementation of construction projects should lead to the efficient drawing of public funds. A functioning business environment in the construction industry is also encouraged by effective administrative support, balanced business conditions for public procurement, the selection of quality construction contractors and sharing of best practices from the implementation of investment construction in the regime of EU legislation and according to proven international contractual standards. Supporting interest in the implementation of public projects helps to provide economic stability of companies and creates space for the growth of the construction industry and the sustainable development of the public and business sector not only in the Czech Republic.

Notice

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Original scientific paper

CAD Based Electric Transporter Path Planning and Production Storage Optimization Using Genetic Algorithm – Industrial Case Study

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Abstract: Štore Steel Ltd. is one of the largest flat spring steel producers in Europe. There are two production lines after rolling – one for flat bars and the other for round bars. The flat bars production generally consists of visual examination, straightening and cutting operation. In addition, heat treatment or magnetic particle testing could be conducted. On the other hand, the round bars production consists generally of straightening, automatic control line control, chamfering and cutting. In addition, heat treatment is possible. For manipulation of the material in the rolling plant, the electric transporter and several cassettes are used. In the paper path planning and production storage optimization (i.e. storage spaces for cassettes) were conducted using genetic algorithm. The production storage is actually the space between main transport passage and individual operations. In the research the universal system using CAD geometry is presented where AutoCAD environment and in-house developed AutoLISP system were used. The production storage – storage spaces for cassettes (location and orientation) with corresponding electric transporter trajectories are represented as CAD objects and thus form individual solution/organism. The organisms undergo simulated evolution. The results of the evolution are compared with actual production storage in the steel plant.

Keywords: genetic algorithm; optimization; path planning; production storage; steel industry

1 INTRODUCTION

Production space is a space primarily intended for production. Any stock of material or products in production is a loss because it binds capital, occupies production's space and requires additional manipulation. Especially products in the production hall are not desirable at all. Nevertheless, intermediate storage places for products in production are a reality. They serve as a buffer for times when the outbound warehouse is out of service or its resources are busy with shipping.

Research on intermediate storage spaces is common in the scientific literature. The buffer allocation problem concerning the size and location of storage between the stages of a flow line is a critical research area in the design of production lines. For example, Nori Prakasa [1] introduced an analytical study of several aspects of two-stage production systems with variable operation times and provision for intermediate storage. The problem of balancing the production system is discussed at some length. It is shown that the production rate improves on allotting a slightly higher load to the less variable stage. Martin [2] extends results of previous models for optimizing interstation buffer capacities for short production lines. His paper refines and extends previous results for lengthier systems and for generally-distributed workstation. His results are presented in a table that provides the line designer with the essential coefficients to find the optimal buffer capacities for many realistic systems. Mak [3] developed a simple optimal buffer capacity model for series production line where the service time variability is described by the normal distribution and the buffers are allocated the same capacity. An expression is derived for the buffer capacity, which minimizes the sum of the delay, inventory carrying, and storage facility costs.

We could continue to summarize the problems discussed in the field of intermediate storage areas in production hall, but most of the scientific work relates to inventories of materials and semi-finished products in production. Discussion about storage of finished products in production hall is not common. Materials and semi-products are mostly stored in crates and standard pallets, which allows the use of agile, standard vehicles like forklifts that do not require much room for manoeuvre when handling transport units. In our case, we are dealing with cassettes measuring 3 × 7 m.

In our case, as a difference with respect to frequent research direction observed in scientific literature, the locations and areas of intermediate storage area are defined. Cassettes are deposited on the ground within the physically limited storage area. Given the intended flow of finished products from production to the warehouse, we are looking for the most appropriate way of stacking cassettes within the space available for intermediate storage for products in production hall. We are slightly constrained by the technical features of the electric transporter with which the cassettes are carried. Because of the specific nature of electric transporter's driving in turns, it is not possible to deposit cassettes completely arbitrarily. To solve the problem of cassette distribution across storage area, we expect answers from scientific paper authors in the field known as the facility layout problem. Layout problems generally differ on layout type, presentation (i.e. shape of facility), constrains (i.e. problem formulation) and also on solving approach [4-6]. Layout presentation is certainly one of the most important features. It can be numerical or geometrical including numerical and/or geometrical constrains [4-6]. Several approaches can be used for its solving including artificial intelligence methods for example taboo search [7], fuzzy logic [8], ant colony [9], particle swarm optimization [10] or genetic algorithms [11]. Despite the variety of methods used in mentioned scientific papers, we did not find a paper that would directly answer our question about the optimal arrangement of cassettes across the available intermediate storage area for finished products, taking into account the limitations of the electric transporter due to its limitations about driving in turns.

2 METHODOLOGY

For solving the problem computer aided design (CAD) and genetic algorithm were used.

The survey regarding CAD geometrical representation of the layout problems reviles several implementations of CAD software for solving problems at assembly [12], path planning [13, 14] to production facility rearrangement [15, 16].

In the paper [17] the CAD system for path planning of extruder was used. Deposition path is constructed from several surfaces using different strategies and can be finally connected into continuous path. In this way the efficiency of extruder can be enhanced.

The article [12] explores the usage of CAD systems for digital data acquisition, motion capture, rendering, virtual assembly, assembly planning, prototyping, training, evaluation and testing of assembly systems.

The authors in [13] used CAD for generation and examination of several robot movement scenarios taking into account ergonomics, quality and productivity. The system was implemented into automotive industry test case.

In the paper [18] CAD system was used for generation of robot trajectories which can be used for off-line automatic motion planning and simulation of robot movements taking into account kinematics and dynamic performances.

The research co-written by the first author of this paper [11] discusses using genetic algorithms for optimal rearranging of the machines in the finishing plant after the available space was drastically reduced due to installation of a new continuous rolling mill line. AutoCAD and in-house developed AutoLISP genetic algorithm based system was used for layout optimization. The machines can be represented as two-dimensional regions or three-dimensional solids without any kind of geometrical restrictions.

Similar article [19] presents CAD based universal solution for cutting stock problem. The parts which are to be cut from stock-material with minimal loss and also the stock-material itself are presented as CAD geometries without any kind of geometrical constraints. In the paper also AutoCAD, AutoLISP and genetic algorithm was used as search strategy.

In this paper, the universal system using CAD geometry is presented. AutoCAD environment and in-house developed AutoLISP system were used. The developed system was used for path planning and production storage optimization (i.e. storage spaces for cassettes) in steel plant in Slovenia. Genetic algorithm was also used. The intermediate storage spaces in production (storage spaces for cassettes (location and orientation)) with corresponding electric transporter trajectories are represented as CAD objects and thus form individual solution/organism.

On the end of this paper, the developed system is presented. Afterwards, industrial case of path planning and production storage optimization is shown. The results of the optimization are compared with the actual production storage space. The paper ends with conclusions and guidelines for future work are given.

3 INDUSTRIAL CASE STUDY

Štore Steel Ltd. is one of the largest flat spring steel producers in Europe. There are two production lines after rolling – one for flat bars and the other for round bars. The flat bars production generally consists of visual examination, straightening and cutting operation. In addition, heat treatment or magnetic particle testing could be conducted. On the other hand, the round bars production consists generally of straightening, automatic control line control, chamfering and cutting. In addition, heat treatment is possible.

4 THE ARCHITECTURE OF PATH PLANNING AND PRODUCTION STORAGE OPTIMIZATION SYSTEM

For manipulation of products in the rolling plant the electric transporter and several detachable cassettes (3 × 7 m) are used (Fig. 1). The electric transporter is first driven below the cassette located along the production line and after it lifts the cassette up from the ground. Once loaded, it enters the main transport path and through it to one of the intermediate storage areas in production. The material is stored in three storage areas in production hall. Fig. 2 shows the location of main transport path and three storage areas (coloured grey) in AutoCAD.

Figure 1 The electric transporter with blue cassette [1]

The proposed approach is created within the AutoCAD system. The AutoLISP/VisualLISP is used as the programming language. The LISP language is incorporated into all contemporary AutoCAD systems. The AutoLISP allows the user to access the AutoCAD's internal drawing database and to manipulate graphical entities. The developed CAD system consists of following modules:

- geometry definition,
- constraint definition,
- evaluation and
- repetitive changing and evolution using different evolutionary operators (e.g. crossover, mutation).

Each cassette represents a part of the storage layout (Fig. 3). It has its location, orientation and individual paths consisting of turns and straight lines leading from/to main transport path. According to technical specification of transportation vehicle, in our case electric transporter, turns can be constructed in a way that is actually feasible. Simplified construction of turns was used in the research.

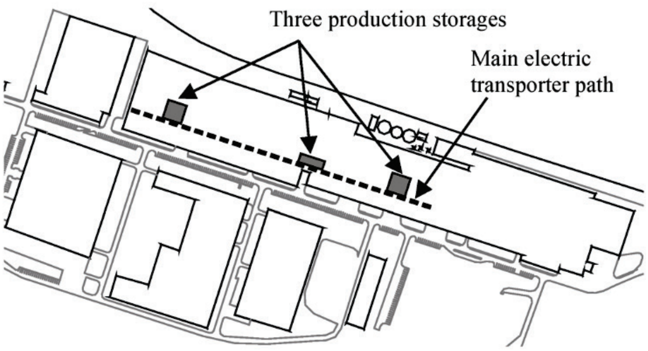

Figure 2 Main transport path and three storage areas in production hall (coloured grey) in AutoCAD

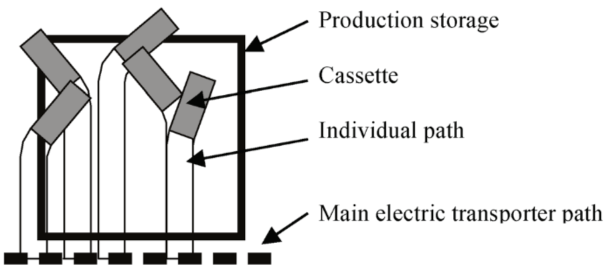

Figure 3 Cassettes and corresponding paths leading from/to main transport path

Regarding constrains it is needed to emphasize that the cassettes should be positioned into the storage area, the orientation can be arbitrary or not and also the minimal turning radius is set according to technical specifications of the electric transporter. The number of the cassettes is arbitrary.

The storage layout is evaluated based on:

- area of all cassettes inside storage area (A),
- intersection area between cassettes (Ac),
- area of cassettes outside storage area ($Acos$) and
- area of electric transporter's paths outside storage area ($Aetos$).

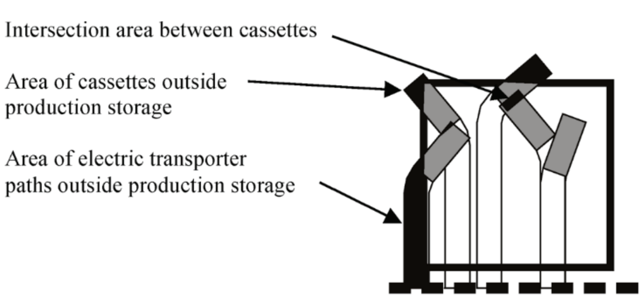

Figure 4 Graphical representation of storage layout evaluation

The evaluation function F is defined as:

$$F = w_A \cdot A - w_{Ac} \cdot Ac - w_{Acos} \cdot Acos - w_{Aetos} \cdot Aetos \qquad (1)$$

where w_A, w_{Ac}, w_{Acos} and w_{Aetos} are corresponding weights, which can be adjusted. In the paper, following weights were used:

$$F = 1 \cdot A - 10 \cdot Ac - 10 \cdot Acos - 10 \cdot Aetos \qquad (2)$$

For the purpose of this research, the genetic algorithm was used as a search strategy. The genetic algorithms are search heuristics, which simulate the natural evolution of living beings [18]. The genetic algorithms have been already used by the authors of scientific papers for solving various problems [21-25].

The organisms (i.e. production storage layouts) consist of genes (i.e. individual electric transporter's paths). Each gene contains the data on location and orientation of the cassette. Based on each cassette location (i.e. reference point) and orientation the cassette, straight path and turn are automatically generated in the AutoCAD (Fig. 5). The best organism in the population represents the best production storage layout.

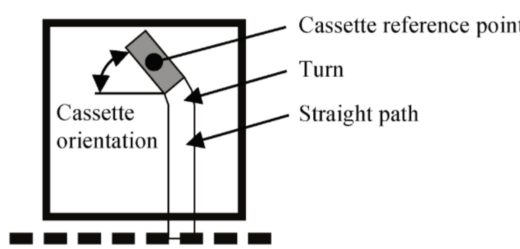

Figure 5 Graphical representation of individual gene

For changing organisms, the following genetic operations were being created: crossover, position mutation, orientation mutation and permutation. In addition, the reproduction operation, which does not change the organisms, is implemented.

The one-point crossover operation for ensuring the exchanging of genetic material between organisms was used. The mutation of position or orientation randomly selects individual cassette in the production storage layout and randomly change its position or orientation. Changes of the orientation of an individual cassette can be made arbitrary or by predetermined angles (e.g. 0°, 45°, 90°). The permutation swaps the positions of randomly selected two individual cassettes, where the orientation of both is intact.

In the paper, the population size of 100 organisms was used. The maximum number of generations was 100 for all runs. For selection of organisms, the tournament method with the tournament size of 4 was used. The maximum number of generations was selected as the stopping criteria for the purposes of this paper. The following probability parameters were selected for the simulated evolution control: 0.4 for crossover, 0.2 for position mutation, 0.2 for orientation mutation, 0.1 for permutation and 0.1 for reproduction probability. 100 independent runs of the system were conducted.

5 THE RESULTS OF PATH PLANNING AND PRODUCTION STORAGE OPTIMIZATION SYSTEM

Based on Fig. 6 storage 1 and 3 are the same. Accordingly, path planning and production storage optimization was conducted for storage 1 and 2, only.

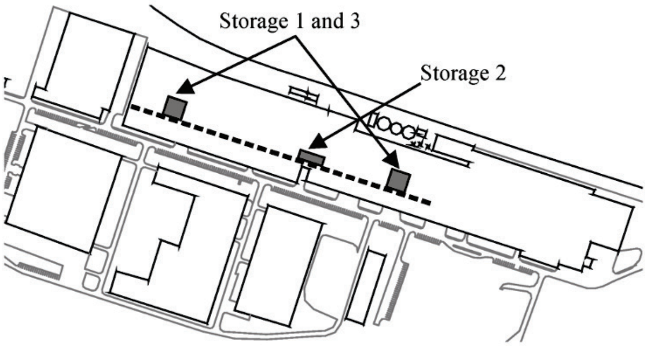

Figure 6 Storages 1, 2 and 3

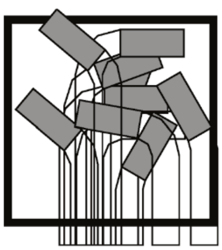

Figure 7 The best production storage layout in randomly generated population

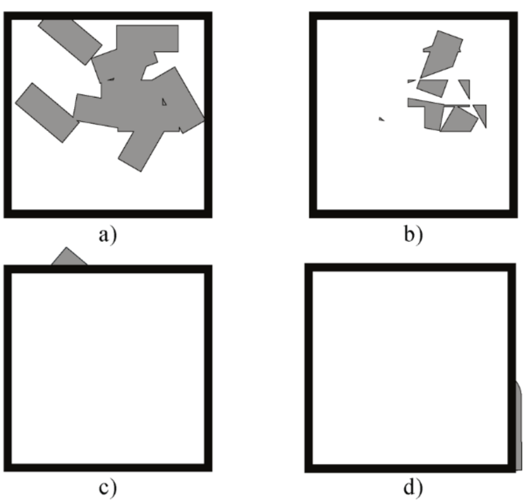

Figure 8 Area of all cassettes in production storage (a), intersection area between cassettes (b), area of cassettes outside production storage (c) and area of electric transporter's paths outside production storage (d) of the best production storage layout in randomly generated population

The run of the system for storage 1 (and 2) started with random generation of population. The best production storage layout is presented in Fig. 7. The area of all cassettes in production storage (A) is 168.24 m^2, intersection area between cassettes (Ac) is 37.75 m^2, area of cassettes outside production storage ($Acos$) is 1.34 m^2 and area of electric transporter's paths outside production storage ($Aetos$) is 20.92 m^2 (Fig. 7). The evaluation function F value for the best production storage layout is thus -431.86.

Fig. 9 shows the worst production storage layout in randomly generated population with evaluation function F value of -4,435.76.

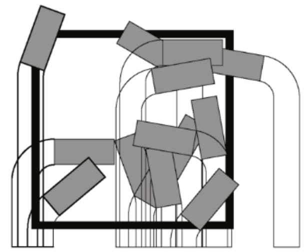

Figure 9 The worst production storage layout in randomly generated population

The best production storage layout was obtained in 93rd generation (Fig. 10). Its evaluation function F value is simply the area of all cassettes in production storage – 252.

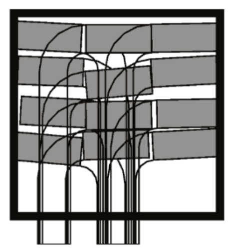

Figure 10 The best production storage layout obtained in 93rd generation

Similarly, the best production storage layout for storage 2 was obtained (Fig. 11). Its evaluation function F value is 126.

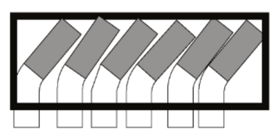

Figure 11 The best production storage layout for storage 2

Figure 12 The actual production storage layout for storage 3

The actual arrangement of the production storage 1 and 3 are actually the same like obtained using genetic algorithm. Fig. 12 shows the actual production storage layout for storage 3.

6 CONCLUSIONS

In this paper, the universal system using CAD geometry is presented. AutoCAD environment and in-house developed AutoLISP system were used. The developed system was used for path planning and production storage optimization (i.e. storage spaces for cassettes) in steel plant in Slovenia. For the optimization, the genetic algorithm was used as a search strategy. The organisms (i.e. production storage layouts) consist of genes (i.e. individual electric transporter's paths). The best organism in the population represents the best production storage layout. For changing organisms, the following genetic operations were used: crossover, position mutation, orientation mutation and permutation. The individual production storage layout was evaluated based on area of all cassettes in production storage, intersection area between cassettes, area of cassettes outside production storage area and area of electric transporter's paths outside production storage. Used evolutionary parameters were:

- the population size: 100,
- the maximum number of generations: 100,
- the tournament method with the tournament size of 4,
- crossover probability: 0.4,
- probability of position mutation: 0.2,
- probability of orientation mutation: 0.2,
- probability of permutation: 0, and
- 0.1 for reproduction probability.

The production storage layout was obtained for two different storage locations. The number of cassettes in the first and in the second storage is 12 and 6, respectively. The obtained layouts were actually the same as they are used in the chosen steel plant in Slovenia. In the future the generation of path trajectories of electric transporter will be enhanced with additional complex manoeuvres (e.g. reverse driving, several different turning radiuses) and 3-dimensional objects.

Notice

The paper will be presented at MOTSP 2020 – International Conference Management of Technology – Step to Sustainable Production, which will take place from 30th September – 2nd October 2020 in Bol, island Brač (Croatia). The paper will not be published anywhere else.

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Original scientific paper

In-Situ Process Monitoring in Additive Manufacturing Using Statistics and Pre-Process Data

Eva Maria Scheideler*, Andrea Huxol

Abstract: Long computation times are a major obstacle for the application of in-situ monitoring in additive manufacturing. This paper presents rapid in-situ monitoring, which returns a control value within typical build times. Observing powder bed fusion processes reveals that unsuitable parameter settings influence the appearance of the molten surface and the surrounding powder bed. The presented research approach evaluates the changing appearance of the exposed layers, in combination with the information from the pre-process about the position and geometry of the components in each layer. Grayscale images are captured with the build envelope camera and examined regarding the grayscale distribution in the critical areas surrounding the component boundaries. The grayscale distribution is then used to predict product quality by using standard statistical methods. The combination of the pre-process data and the fast analysis of the grayscale distribution allows promptly calculating a performance indicator for required process intervention and control.

Keywords: energy density; image processing; layer check; part quality; Selective Laser Melting

1 INTRODUCTION

In many industries, additive manufacturing (AM) is increasingly focused on the production of final parts, as it has the potential to solve certain problems in the context of decreasing lot sizes and product individualization [1]. To exploit the full potential of the technology, AM has to be completely integrated into the production process. This requires certain changes in the production process itself. For instance, AM machines have to be embedded into industrial process chains by increasing the level of automation and developing consistent data models [2].

Furthermore, the process quality of AM processes has to be improved to allow the production of reliable part quality. The implementation of process monitoring systems can help to improve the limited or unproven repeatability of the build process. At the current state of research and in industrial applications, many AM machines are already equipped with certain process monitoring tools. Though the existing process monitoring solutions show a potential to improve the reliability of the SLM process, they are not yet fully applicable for process control [3].

2 SELECTIVE LASER MELTING

The term additive manufacturing (AM) describes different technologies that create parts directly from three-dimensional CAD data, by additive joining of volume elements, usually in the form of layers [4]. Today, several AM technologies show a level of maturity that enables the application in series production. One of these is Laser Powder Bed Fusion of Metals (M-LPBF). In principle with this method, a layer of powder is spread onto a build platform and afterward selectively fused by use of a laser beam in the area where the part is to be generated. Next, the platform is lowered minimally and a new layer is spread and fused again. This procedure is repeated until the final height of the product is reached. Thus, the product is generated layer by layer, surrounded by the residual powder.

A large number of parameters and factors influences the outcome of the M-LPBF process, during the in-process as well as during pre- and post-processes. For the in-process, these parameters include the definition of the exposure strategy, e.g. hatch definition, laser energy and scan speed, but also the environmental control of the build chamber, including gas flow, atmosphere and temperature. The extensive number of influencing parameters hinders the development of suitable methods for process control and quality assurance, especially as the quantitative correlation between the parameters, the process signatures and the process results are mostly unknown [5]. Thus, quality control measures for M-LPBF are largely limited to quality inspection.

Current quality management (QM) techniques in traditional manufacturing are based on statistical analysis and require a large number of identical tests to create a sufficient database. As AM technologies are often applied for the production of small lot sizes, the process will not deliver an appropriate number of parts to apply these methods. Together with the limited availability of design rules and specified tolerance classes for AM technologies, it is extremely difficult to achieve a proven process capability [6]. The implementation of process monitoring systems in M-LPBF can help to evaluate and improve the repeatability of the build process. In the first stage, it can enable the identification of defects during the build process, in a final stage this may lead to the development of closed-loop control systems [7].

Various approaches towards process monitoring for additive manufacturing are presented in research, mostly using optical measurement methods for different indicators. For several of these approaches, it is shown, that the measured signals change in areas, where parts show defects. Nevertheless, full proof of applicability for inline process monitoring is not yet available [3].

In commercial M-LPBF machines, different process monitoring solutions are integrated. These systems can be divided into five categories: condition monitoring, powder bed monitoring, laser power monitoring, melt pool monitoring and documentation of the individual layer surfaces. Condition monitoring systems use a variety of sensors to collect data on the general operation of the machine and supervise safety-relevant parameters. All other categories of monitoring systems are based on optical measurements. Photo diodes are used for monitoring the laser power and certain emissions from the melt pool. For monitoring of larger areas, like in powder bed or layer surface monitoring as well as monitoring the size and shape of the melt pool, camera systems are applied.

At the current state, these systems are mainly collecting data, which is manually evaluated afterward. Changes in the signals are used as indicators for final part inspection. For applications of M-LPBF in series production, it is possible to compare the data of a larger number of parts to come to threshold values. However, this is not feasible for individual parts or very small lot sizes. Here, it is necessary to find a possibility to define general thresholds [3].

Furthermore, the large amount of data that is collected by the process monitoring tools is difficult to handle. Current systems mostly collect the data during the build process and analyse the entire data after the process is completed.

3 RESEARCH APPROACH

Currently, a lot of experience is required to operate an M-LPBF machine and produce high-quality parts. The experience gained by the operator can enable the identification of certain problems during the build process. For example, it is possible to identify parts with a very high energy input that have a high risk of curling or forming an uneven surface. This experience can be mimicked by image processing solutions. The presented research approach aims to develop an image processing methodology applicable to identify parts that are likely to show curling due to high local energy input. The methodology is intended to use simplified models for the calculation to achieve short processing times and thus, enable the application for in-process monitoring and control. This article provides the description of a practical implementation and solutions from the area of production.

3.1 Preconditions

An experimental design is prepared to identify influencing parameters on the part porosity. Therefore, cubes of 8 × 8 × 8 mm³ are built from a CoCrW dental alloy. The machine used in this experiment is a Realizer SLM 125 with a build chamber of 125 × 125 × 200 mm³. For documentation purpose, the machine captures images of each layer after spreading the powder layer and after the melting process by a monochromatic digital camera with a resolution of 1280×720 pixel.

The layer thickness is kept constant at 25 µm and the hatch is changing between X-hatch in odd layers and Y-hatch in even layers. All parts are built with different parameter combinations resulting in different volumetric energy densities. The volumetric energy density E is calculated according to Eq. (1)

$$E = \frac{P}{\frac{d_p}{t_e} \cdot d_l \cdot d_h} \tag{1}$$

Where P is the laser power in Watt, d_p is the point distance in mm, t_e is the exposure time in s, d_l is the layer thickness in mm and d_h is the hatch distance in mm. The parameters laser power, point distance and exposure time are varied between three different values each, which results in volumetric energy densities between 30.00 and 185.33 J/mm³. The observation of the build jobs reveals irregularities for the samples with the highest energy densities, as shown in Fig. 1.

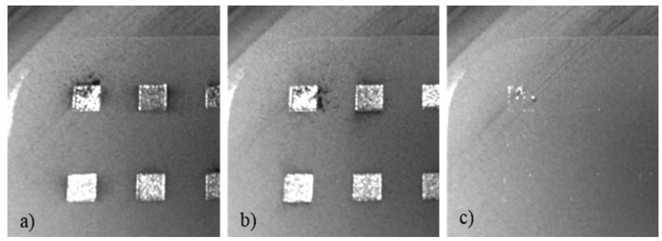

Figure 1 Formation of a curled part during the SLM process
a) part height 0.65 mm, b) part height 0.675 mm, c) powder layer at part height 1.125 mm. [8]

For the top left sample in the pictures, an accumulation of burnt material is visible. Its position depends on the hatch direction (Fig. 1a and Fig. 1b). In successive layers a curling effect of the surface becomes obvious (Fig. 1c)) that can cause damages on the powder spreading system. These parts have to be deleted from the further build process.

3.2 Image Processing

The aim of the research approach is to develop an image processing methodology that can be applied to identify parts that are likely to show curling due to high local energy input. The methodology is intended to use simplified models for the calculation to achieve short processing times and thus, enable the application for in-process monitoring and control.

In a first approach, the images captured after the melting of the individual layers are used to identify areas where burnt material is accumulating near parts with high energy input. To identify differences between the good and the substandard parts, images from the experimental setup as described in 3.1 are analysed. Therefore, the surrounding areas of the cubic sample are separated into North, East, South and West regions, as shown in Fig. 2.

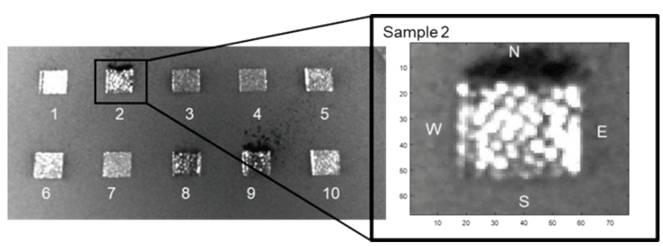

Figure 2 Images processed for identification of burnt material. [8]

The four areas are selected corresponding to the hatch direction, as it has an influence on the position where the burnt material is deposited. In the current setup, in which X- and Y-hatches are used, the accumulation of burnt material is found either in the North or in the East area, depending on the layer.

For each of the areas, the grayscale distribution is calculated and presented in the form of a histogram. A curve fitting with a standard Gaussian curve is applied to each of the histograms, Fig. 3. These show different results for areas with and without burnt material. The widths of the curves differ, as represented by the coefficient c_1. A larger value indicates a larger width. Furthermore, the goodness of fit is different, which is represented by the R^2 value. A larger value indicates a better fit of the curve.

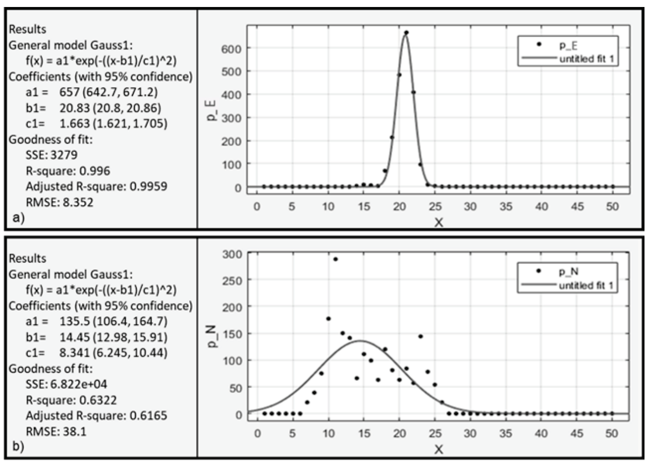

Figure 3 Grayscale distribution and fitting of a Gaussian curve for a) East and b) North of sample 2 [8]

By combining these to values an indicator I_b for the presence of burnt material can be calculated according to Eq. (2)

$$I_{\mathrm{b}} = \frac{c_1}{R^2} \tag{2}$$

For the East area, where no burnt material is present, the indicator is $I_{bE} = 1.7$, whereas the indicator for the North area is $I_{bN} = 13.2$. A clear difference between the indicators is obvious. A further advantage of using a relative value as an indicator is that it filters the effect of different lighting situations in different areas of the build envelope, which can be seen in Fig. 2. These differences occur due to the arrangement of camera and light sources relative to the build platform, which is not concentric. Thus, a comparison of absolute values delivers results dependent on the part position.

3.3 EXTENSION TOWARDS VARYING CROSS SECTIONS

In chapter 3.2 the principal calculation method for the indicator is shown. The procedure is shown with the simple example of a cube that has edges parallel to the pixel matrix of the image. Furthermore, the cross sections are constant over the entire build height. This special situation makes it easy to evaluate the edges around the melted parts from the photo sections. However, if the components are more complex in their basic structure and the exposed areas change over the component height, this must be taken into account when determining the North, East, South and West areas to be evaluated. The scanning direction of the hatch in the respective layer is also to be considered.

The shape of the histogram of areas with burnt material depends not only on the amount of burnt material, but also on the size of the partial area considered in principle. If, for example, a very large partial area is analysed in which only a small area segment is covered with burnt material, this will hardly be noticeable in the histogram and in the evaluation proposed in chapter 3.2. Furthermore, observations have shown that small melted areas also result in smaller areas with burnt material [15]. This means that the size of the partial areas to be investigated has to be determined depending on the structure and shape of the component to be built.

The following procedure has been developed for this situation: The position and shape of the individual components per layer is known from the pre-process (Fig. 4).

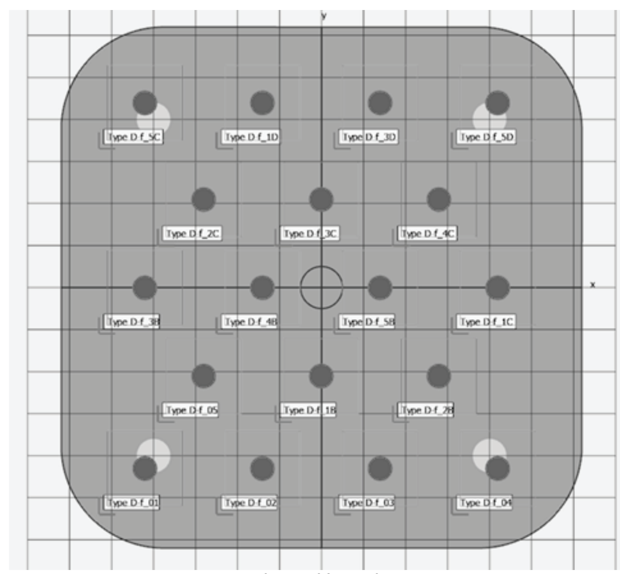

Figure 4 Image of layer 98 mm from pre-process.

Based on this information, the size of the partial area to be exposed can be determined. Classical image processing tools can automatically determine the size, position and shape of the partial areas to be exposed layer by layer. In addition, information about the hatch strategy can be obtained to identify relevant areas for evaluation.

Masks are created here from the pre-process images. If these masks are overlaid with the images of the build envelope, the actual components are faded out and thus only unexposed areas (powder bed) are visible for the grayscale analysis.

It should be noted that the images of the build envelope are in distorted perspective, as the camera is located not centered in the build envelope at a distance of 22 cm from the powder bed surface, while the images from the pre-process are generated by the computer and do not show any perspective distortion. In order to be able to overlay the generated masks with the image of the build envelope, the image distortions must be corrected by image transformations (Fig. 5).

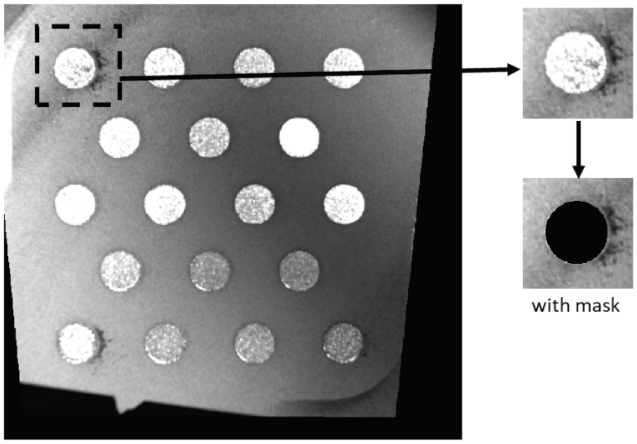

Figure 5 Transformed image a) Detail b) Detail with mask.

3.4 Evaluation

For evaluation, the developed method is applied to a successive build job. In this build job round tensile test specimen (Fig. 6) with conical clamping heads according to DIN 50125 – D 5 × 25 [14] with an increased parallel length of 80 mm (total length of 104 mm, maximum clamping head diameter of 18 mm) are built. The support in this build job is 4 mm high. Therefore, the overall height of the build job is 108 mm.

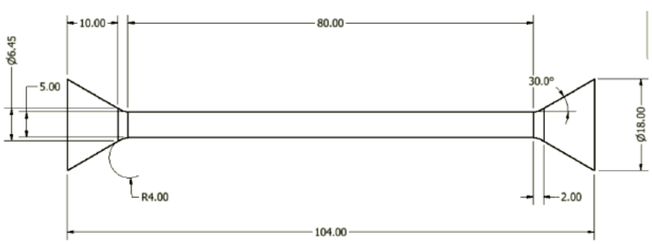

Figure 6 Tensile test specimen [9]

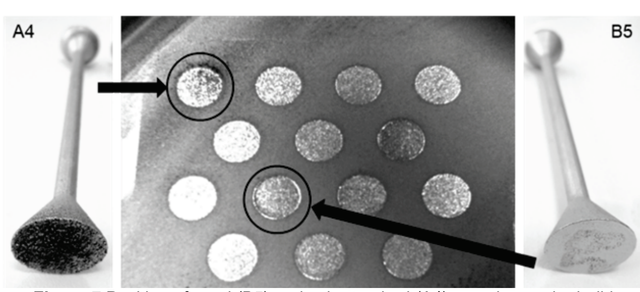

Figure 7 Position of good (B5) and sub-standard (A4) samples on the build platform [8]

The evaluated images are captured during the production of the parallel section and the upper clamping head. Due to different parameter settings good and sub-standard parts are produced in this build job, as shown in Fig. 7.

An accumulation of burnt material is clearly visible in the area of the sample A4. Furthermore, the final part shows a rather strong deformation of the surface, resulting in a sub-standard quality of the part. In comparison to this, the sample B5 shows a smooth surface and no disturbances of the surrounding powder bed are visible during the build process.

The developed image processing method is applied to the images form the layer height 73 mm to 108 mm, which includes 1070 successive layers. Fig. 7 shows the resulting indicator I_b for the analysed layers of the sample A4. The position of the deposited burnt material is depending on the hatch direction and changes between the layers with X- and Y-hatch. To enable an automated calculation of the indicator, it is calculated for all four regions in every layer. For further evaluation, the area with the lowest R^2 value is considered in each layer. Those values are represented by the graph in Fig. 8.

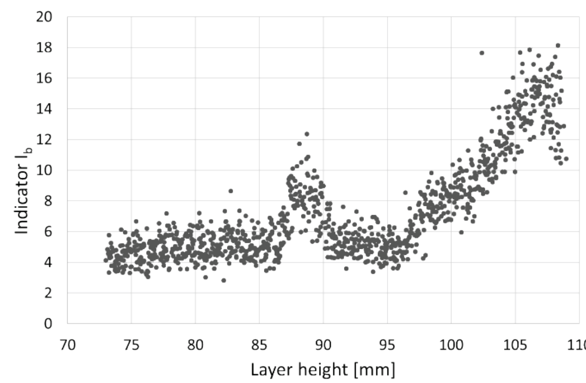

Figure 8 Indicator I_b of sample A4 (Layer height 73 mm to 108 mm)

From the diagram, it can be seen that the I_b value has a certain fluctuation margin, therefore a moving average over 50 layers is used for further evaluation. Fig. 8 shows the moving average of the indicator I_b for the samples A4 and B5 for the layer height from 73 mm to 108 mm. With these signals, the changes during the production of the individual components can be easily observed.

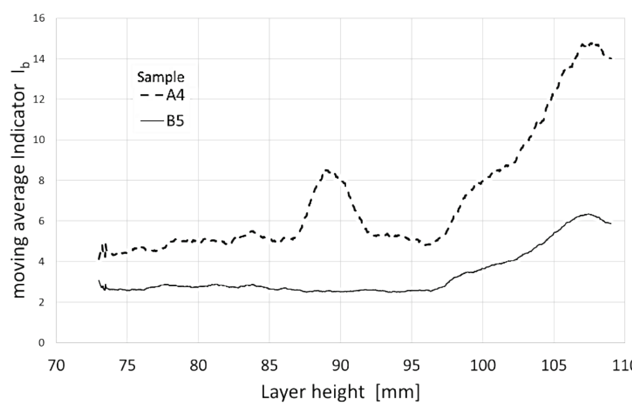

Figure 9 Moving average of indicator I_b of sample A4 (height 73 mm to 108 mm)

The comparison of the values shows a significantly different behaviour of the indicator values for the two samples (Fig. 9). The indicator for sample B5 is at a low level. There is an increase of the indicator from the height where the constant cross-section merges into the conic area. The indicator curve of sample A4, however, shows clear differences. The indicator value already starts at a higher level. At the layer height of 88 mm, the value increases, reaches a local maximum and decreases again. In this range the cross-section of the tensile sample is still constant. By closer inspection of the images, a grey haze in the powder can be seen in the area of this sample (Fig. 10a and Fig. 10b). There is a clear second increase of the values in the area of the conic clamping head. Here, the cause is an accumulation of burnt material (Fig. 10d).

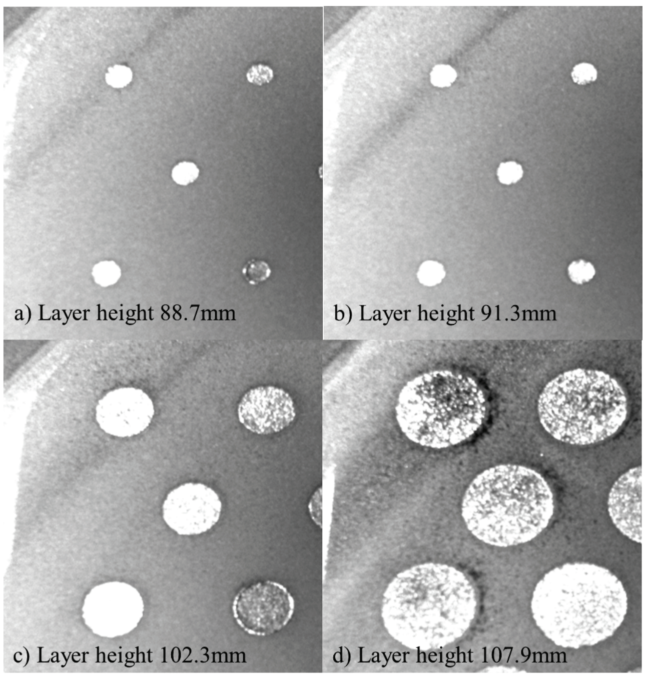

Figure 10 Captures of part A4 (top right) at different layers

This dissimilar behaviour of the different sections of the sample is likely to be caused by the different size of the exposed cross sections. While the inserted energy per square millimetre is the same, the overall amount is smaller due to the smaller cross-section in the layers representing the parallel length. Furthermore, the heat conduction is influenced not only by the exposed area in the layer itself but also by the volume of solidified material in the previous layers.

4 CONCLUSION AND OUTLOOK

The presented image processing method is currently applicable to identify parts which are likely to cause severe problems in successive layers. As only a limited area of the powder bed surface is analysed, applying standard procedures of image processing, the processing time is relatively short. Integrating this evaluation into the process monitoring tools of an M-LPBF machine can help to identify parts with problematic energy input before they start to grow out of the powder bed and may cause damages to the recoated system.

To define the areas for monitoring, it is necessary to know, which parts of the powder bed are exposed in each layer. For further reduction of the processing time, additional information on the direction of the hatch scan can be included. As all this information is available before the start of the build job, the areas of interest can be calculated for each layer in advance.

One of the next steps is to work out which signal changes lead to which actions in the build process. A first step could be to switch off individual problematic components and continue building the rest of the build job.

A further possibility is the local reduction of the energy introduced into a component in the next layers as soon as a possible fault is detected [7].

Investigations have shown that the volumetric energy density in relation to a component depends not only on the laser power but also on movement parameters of the laser [10]. In order to be able to reduce the energy introduced into the component, further investigations into the effects of the parameters of the volumetric energy density must be carried out.

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Notice

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Preliminary communication

Dimensional Structural Mass Optimization of a Welded I-Profile Bridge Crane Girder

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Abstract: This paper presents the methodology for the development of an optimization model for the optimization of the cross-section dimensions of a bridge crane girder designed as a welded I-profile. To carry out this optimization, the CAD/CAE software package CATIA V5 was used. In order to develop an optimization model, a CAD geometrical model and structural analysis model were developed. Optimization was carried out by the iterative method using a simulated hardening algorithm. Additionally, the optimization process is carried out by using the PEO (Product Engineering Optimization) CATIA module that contains tools for setting the optimization criteria, design parameters, constraints, and algorithms. The goal of the optimization is to achieve the minimal mass of the girder, while satisfying all functional and geometrical constraints. As a result of the optimization process, minimal girder dimensions were obtained and due to that, a minimal amount of material can be used for the manufacturing of the girder.

Keywords: crane girder; optimization; parameters; simulated hardening

1 INTRODUCTION

Today, engineers, designers and researchers always try to optimize theirs designs so that a minimum amount of material can be used, or that minimum stresses can be achieved. The allowed stresses are pushed to their minimum limits. If someone wants to optimize his or her part, from the aspect of the minimum mass or minimum stresses, they need to know the precise stress distribution inside the loaded part. Computer aided optimization (*CAO*) is connected to and based on the numerical analysis processes.

The goal of this paper and this research is to present the methodology for the development of an optimization model for the optimization of the cross-section dimensions of a bridge crane girder designed as a welded I-profile. A detail description of the possibilities and characteristics of a *PEO* (*Product Engineering Optimization*) module for the structural optimization in a *CAD/CAE* (*Computer Aided Design/Computer Aided Engineering*) software CATIA (*Computer Aided Three-dimensional Interactive Application*) is presented. Firstly, it is necessary to develop a *CAD* (*Computer Aided Design*) parametric model and numerical model of a bridge crane girder. Characteristic design dimensions of an I-profile are chosen as optimization parameters.

Dimensioning is the process of choosing the right dimensions of a machine part in correlation to the function of that part, its mechanical properties, stiffness, standards, price, etc. That correlation is not always exactly (mathematically) known. Because of that, the mathematical function (the goal function of optimization) is not always easy to set. In this case, the only way to carry out optimization is to use the iterative process. When using the iterative process, it is possible to come close to an optimal design by taking into consideration all of the above-mentioned constraints. It is only possible to carry out this type of iterative process by using computer software. Sometimes, in terms of classical optimization problems, the iterative process is carried out only for the most important constraints, other constraints are chosen as constant values. Speed is not the only benefit of using computer software for the optimization. Optimization via computer software can optimize parts for multiple constraints simultaneously. Additionally, by using computer software, it is possible to carry out optimization for the assembly, not only for one part. The results of optimization for one part can be used as input data for another part in the assembly. [1–2].

The subject of the research in this paper is the optimization of the cross-section dimensions of a bridge crane girder designed as a welded I-profile. Bridge cranes have two main girders with the rails for wheels movement. The ends of the main girders are fixed to transverse supports, which have wheels for the movement of the entire bridge crane (Fig. 1).

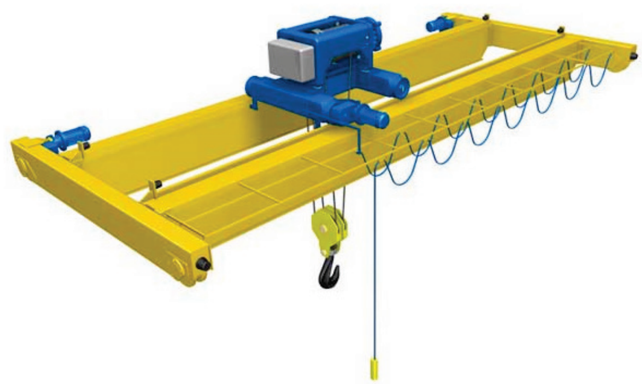

Figure 1 Bridge crane with two main girders

There are a lot of research papers about the structural optimization used in the design process. Usually, it is the topology optimization, or the optimization of the shape and size [3-12].

2 STRUCTURAL OPTIMIZATION

Optimization is the process of obtaining the best solution for the given constraints. The main goal of engineers and designers during the design process is to minimize the usage of the used materials or to maximize the benefits. The above-mentioned statement must be formulated as a mathematical function of some unknown variables. Optimization can be defined as a mathematical problem of the minimization or maximization of the function.

There are many different methods for optimization. The most common method for engineers is the method of simulated hardening. This method is based on the process of metal cooling during hardening. It was developed by *Kirkpatrick*, *Gellat* and *Vecchi* [13].

Simulated hardening is the stochastic method for searching for a good approximation of the global minimum of the function. The simulated hardening method is based on the process of the heating and controlled cooling of metal materials with the goal of exerting influence on the metal structure and inside errors. This algorithm can find the global minimum in a certain amount of time [14].

The algorithm begins with the initial design vector X_1 (iteration number $i = 1$) and a high value of the temperature T. By random generation of a new point X_{i+1}, the nearby first point, the value of the goal function can be calculated by using the following equation:

$$\Delta E = E_{i+1} - E_i = \Delta f = f_{i+1} - f_i = f(X_{i+1}) - f(X_i) \tag{1}$$

If f_{i+1} is smaller than f_i (negative value of Δf), point X_{i+1} is accepted as a new design vector. If Δf has a positive value, point X_{i+1} is accepted as a new design vector with the probability of $e^{-\Delta E/kT}$. That means that if the value of a randomly generated number is bigger than $e^{-\Delta E/kT}$, point X_{i+1} is not accepted as a design vector. With this process, one iteration of the optimization process is finished.

If the point X_{i+1} is not accepted, the generation process of the new point is based on the *Metropolis* criteria:

$$P(E_{i+1}) = \exp\left(\frac{\Delta E}{kT}\right) \tag{2}$$

For the simulation of the thermal balance achievement on every temperature, a number of new points is selected (n) X_{i+1}. These points must be analyzed for the defined values of temperature.

When a number of new design points X_{i+1}, analyzed for the defined value of temperature, become bigger than the number n, the temperature T is reduced by an already defined factor c ($0 < c < 1$) and the whole process repeats. It is considered that the process converges when the value of temperature is small enough or when the change of the value of the goal function Δf is small enough.

For good optimization, the most important thing is to formulate the optimization problem correctly. An optimal solution will have satisfactory results only if the optimization problem is formulated in the right way.

For the design optimization, a five-step procedure for the optimization problem formulation is usually used. The first step is to define the optimization goal. In this case, the optimization goal is to find the optimal dimensions of the girder cross section to achieve the minimum mass of the girder for the constant length and loading capacity. Stresses in the girder must be lower than the allowed stresses for the material of the girder. The maximum displacement should not be bigger than $L/1000$. Additionally, it is necessary to check the possibility for lateral torsional buckling [15, 16].

The second step is to collect the data about the optimization problem. A static schematic diagram is shown in Fig. 2a. The length of the girders is 16 m and the maximal load of the bridge crane is 20 T.

For the numerical finite element analysis and for the optimization analysis of the girders, the *CAD/CAE* system *CATIA* is used. The material of the bridge crane is stainless steel S235.

In the third step, it is necessary to define the parameters that describe the system. The mass of the girder is in the function of the volume (dimensions) of the girder and material density. The dimensions of the girder cross section are shown in Fig. 2b, and these dimensions are taken as design parameters.

The length of the girder L and the material (density of the material ρ) are constant during the optimization process. Due to that, they are removed from the optimization problem formulation. The same applies to the rails. Rails have standard dimensions ($a = 50$ mm and $c = 40$ mm). The rest of the girder cross section dimensions (b, t_1, h and t) are free parameters and they are taken as the design parameters for optimization.

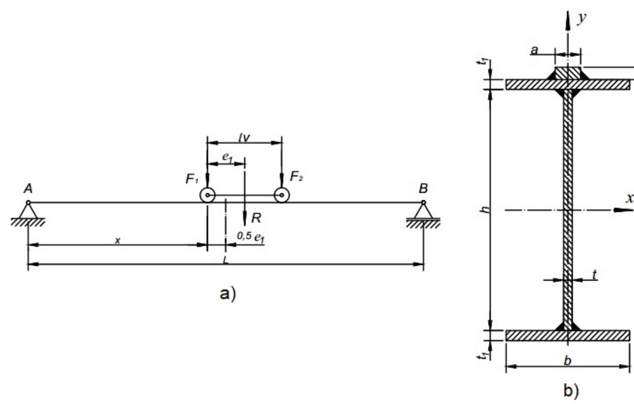

Figure 2 a) Schematic diagram of the bridge crane; b) Girder cross section

The fourth step is to define the goal function. The goal of the optimization is to find the dimensions of the girder cross section, which will give the minimum mass of the girder for the applied constraints. The mass of the girder can be expressed as the function of the design parameters.

$$f(b, t_1, h, t) = m = A \cdot L \cdot \rho \cdot g \tag{3}$$

In the last step of the optimization, it is necessary to define the constraints. Constraints are applied in the form of the allowed values for the maximum stress, deflection and lateral torsional buckling.

Moreover, constraints must be applied in the form of the values for the minimum dimensions which the cross-section needs to have.

3 DEVELOPMENT OF CAD AND NUMERICAL MODELS

During the development of the 3D CAD model, the goal is not just to get the visualization of the design, but also to get a functional 3D CAD model. A functional 3D CAD model can be developed by using parametric modelling.

The term parametric design is associated with the parametric systems and it is defined as "a process of designing with parametric models in a virtual surrounding where the geometrical and parameter variation are natural" [17-19].

The parametric model of a bridge crane girder is developed by using the CATIA software package. First, the 3D model of the bridge crane girder is developed by using the geometrical and dimensional constraints. After the 3D model is developed, parametrization of design parameters, defined in Chapter 2 of this paper, can be carried out. An example of the relation between the parameters is shown in Fig. 3.

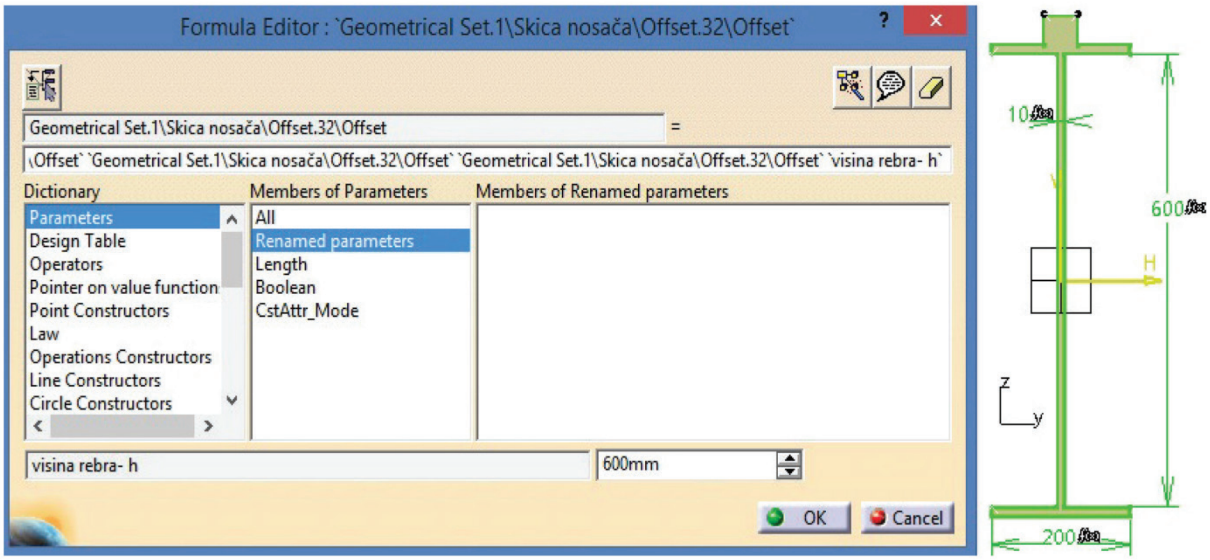

Figure 3 Relation between parameters

The finite element structural analysis via the *Generative Structural Analysis* in the software package *CATIA* module is carried out by using the above-mentioned developed *3D CAD* parametric model. The first step in the process of the finite element structural analysis is to carry out the discretization of the girder by using finite elements [20-26].

The second step is to apply the constraints. In this case, the girder is supported at both ends. One end has all translations fixed and all rotation allowed, the second end is a movable support with all translations and rotations allowed (Fig. 2a).

The third step in the process of the finite element structural analysis is to apply the loads on the girder. All loads from real working conditions must be applied to the girder. The girder is loaded with their own weight, the weight of the load which it is carrying and the weight of the winch.

The results of the finite element structural analysis, carried out on the initial 3D CAD model, are the values of the displacements and Von Mises stresses. These values will be used as the constraints for optimizations (Fig. 4).

As it has earlier been mentioned, one of the constraints should be the value for lateral torsional buckling. To get this value, it is necessary to carry out a new structural analysis for this case. The static analysis of lateral torsional buckling is taken as a referent analysis.

The analysis of lateral torsional buckling in the CATIA software package gives 10 modes of the torsional twist. Only the first three or four modes are important in practical applications [27]. For the bridge crane girder, only the first mode is taken into account as a relevant one. This will reduce the time of calculations (Fig. 5).

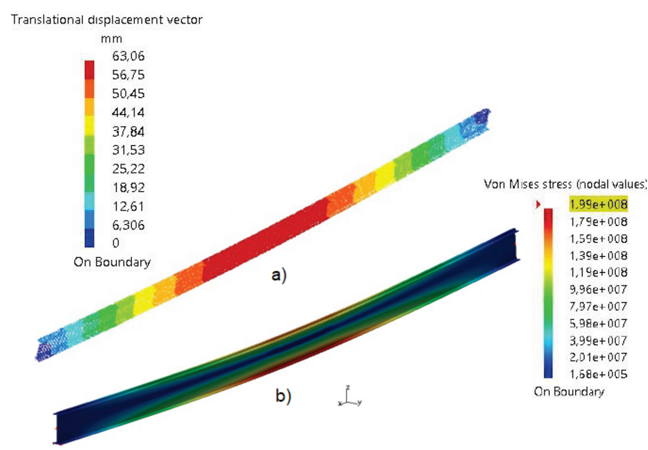

Figure 4 Results of a static finite element analysis on the initial 3D model of a bridge crane girder: a) vector of displacements, b) Von Mises stresses

Fig. 5a shows the deformation of the girder without lateral bracing during lateral torsion buckling loads. The coefficient of deflection for this case is 0.324. Fig. 5b shows the deformation of the girder with three lateral bracings. For this case, the coefficient of deflection is 4.45. It can be noticed that deformation is significantly bigger in the case where lateral bracings are not applied, i.e. girder will deform because the coefficient of deflection is lower than 1.

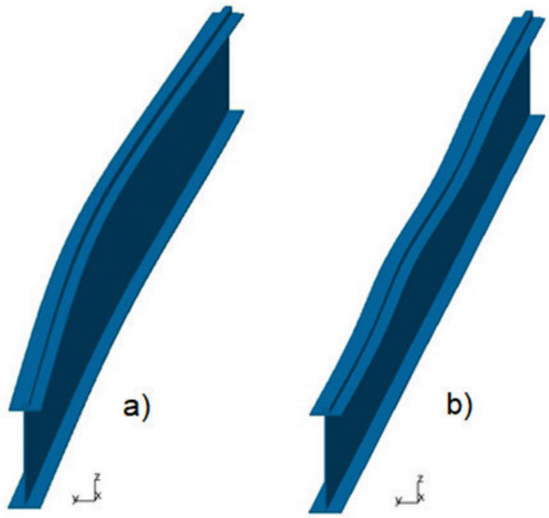

Figure 5 Deformation of the girder; a) without lateral bracing, b) with three lateral bracings

4 DEVELOPMENT OF AN OPTIMIZATION MODEL
4.1 The Mathematical Model

For the development of an optimization model, the nonlinear *SUMT* (*Sequential Unconstrained Minimization Technique*) method was used. According to this method, the so-called penalty functions are introduced. In these processes, approximation is carried out by adding the penalty member to the goal function in the area where constraints are not satisfied [28]. For the goal function, a girders mass is selected, which has the following form:

$$f(b, t_1, h, t) = (2b \cdot t_1 + h \cdot t + a \cdot c) \cdot L \cdot \rho \cdot g \tag{4}$$

where: b, t_1, h, t, a and c - are shown in Fig. 2, ρ – the specific mass of steel, g - speed of gravity.

The constraints that the design should meet:

- flanges:

$$\begin{aligned} &\sigma_v - \upsilon \cdot \sigma_{u,p1} \geq 0 \\ &\sigma_v - \upsilon \cdot \sigma_{u,p2} \geq 0 \\ &t_1 - 1.2t \geq 0 \\ &2t - t_1 \geq 0 \end{aligned} \tag{5}$$

- the web:

$$\begin{aligned} &\sigma_v - \upsilon \cdot \sigma_{u,r} \geq 0 \\ &\sigma_{ux} - \upsilon \cdot \sigma_{s,r} \geq 0 \\ &\sigma_v - \sigma_{ux} \geq 0 \\ &t - 5 \geq 0 \end{aligned} \tag{6}$$

- deflection:

$$w_d - w \geq 0 \tag{7}$$

where: σ_v - the tension on the extension limit, $\sigma_{u,p1}$ - maximal tension in the upper flange, $\sigma_{u,p2}$ - maximal tension in the lower flange, $\sigma_{u,r}$ - maximal tension in the girders web, $\sigma_{s,r}$ - flexion tension in the girders web, σ_{ux} - border tension on buckling, υ - the level of security.

For resolving the cost function minimization problem, the Eq. (4) with constraints, Eq. (5), Eq. (6) and Eq. (7), which have a form of inequality $c_j = (b, t_1, h, t) \geq 0, j = 1, 2,, \ldots, m$, and a penalty function method SUMT are used. With the introduction of the penalty function here, a new cost function is formed, Eq. (8) without limitations, and then the function minimum is determined:

$$\Phi(b, t_1, h, t, r) = f(b, t_1, h, t) + r \sum_{j=1}^{m} \frac{1}{c_j = (b, t_1, h, t)} \tag{8}$$

To solve the problem, a previously made computer program in *FORTRAN* was adjusted [29].

4.2 The Numerical Model

The same problem was solved numerically, and for that purpose, the *CATIA* module *Product Engineering Optimizer* was used. The module has iterative methods that can be used for any parameter [30]. In this case, the so-called simulated hardening algorithm is used. This algorithm was chosen because the goal function is unknown, and because this algorithm can avoid local minimums and find the global maximum. For this algorithm, the speed of convergence can be chosen [31-33].

After the definition of the goal function, design parameters and constraints. The results of the optimization can be presented in the form of diagrams for different combinations of design parameters. (Fig. 6 and Fig. 7). Fig. 6a shows the changes of the goal function in the form of the value of mass for all iterations. In the same figure, a diagram of the best solution (the best value of the goal function) is also shown. Fig. 6b shows the changes of the height of the web and the deviation of the values of the deflection from the allowed values during the iteration process. It can be noticed that when increasing the values for the height of the web, deviation is going close to zero, which means that the deflection has lover values. From Fig. 7a, it can be noticed that the maximal deflection is 15.96 mm, which means that the constraints for deflection are fulfilled.

Furthermore, from Fig. 7b, it can be noticed that maximal stresses occur at the lover part of the girder and that the maximal value is 82.4 MPa, which is lower than the constraint of 160 MPa.

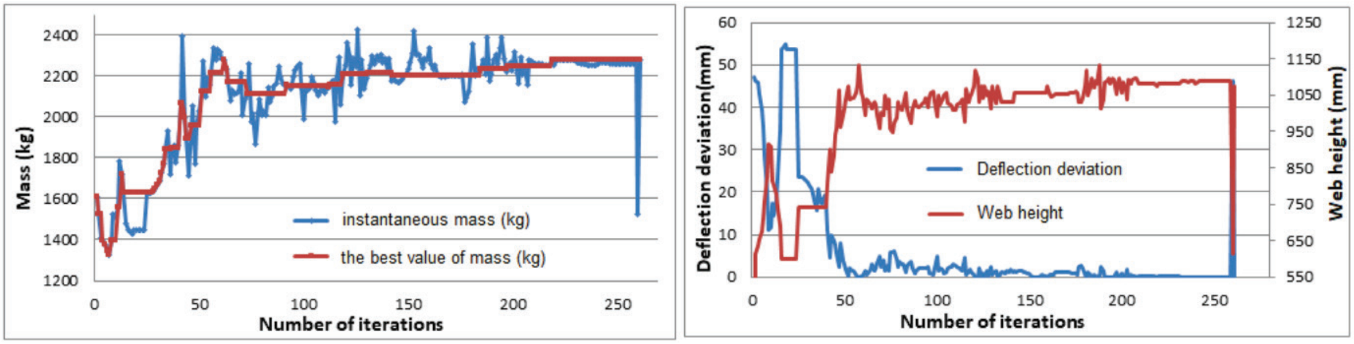

Figure 6 Parameter changes during the iteration process a) relation between the current and best mass of the girder b) relation between deflection and the height of the web

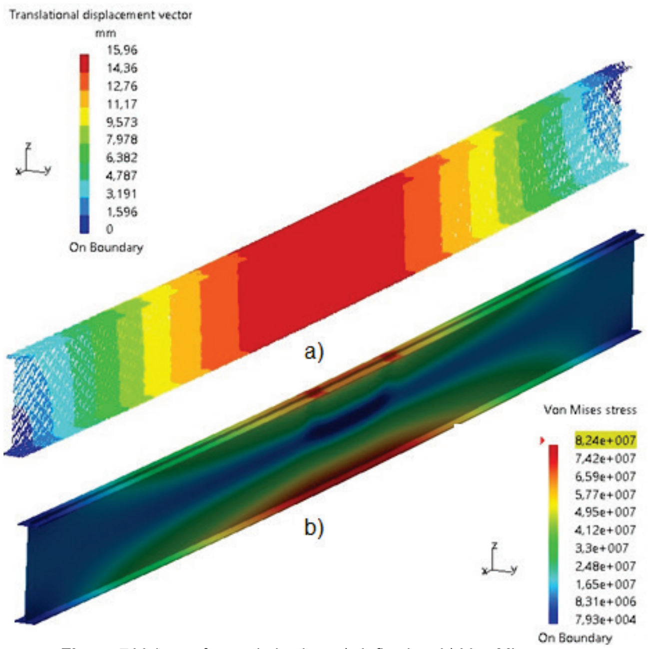

Figure 7 Values after optimization; a) deflection, b) Von Mises stress

5 RESULTS

Fig. 8a shows diagrams of the dependency of the mass of the girder to the number of lateral bracing for different lengths of the girder. It can be noticed that the number of lateral bracing does not have a significant effect on the mass of the girder. This is an important fact, because for the lengths of 16 m, 20 m, and 25 m of the girder, the optimization algorithm could not find the solution without using lateral bracing. The constraint for lateral torsional buckling could not be fulfilled. After adding only one lateral bracing at the middle of the girder, optimization was carried out successfully.

Fig. 8b shows the correlation between the mass of the girder and the allowed deflection for the length of 16 m, the free length of torsional buckling of 4 m and the ratio of h/t = 120. The calculation is carried out for the loads of 100 kN and 200 kN and the ratios of L/f = 1000, 950, 900, 850, 800, 850. By increasing the value of the allowed deflection, the needed stiffness of the girder is reduced, which means that the girder can have smaller dimensions and a lower mass.

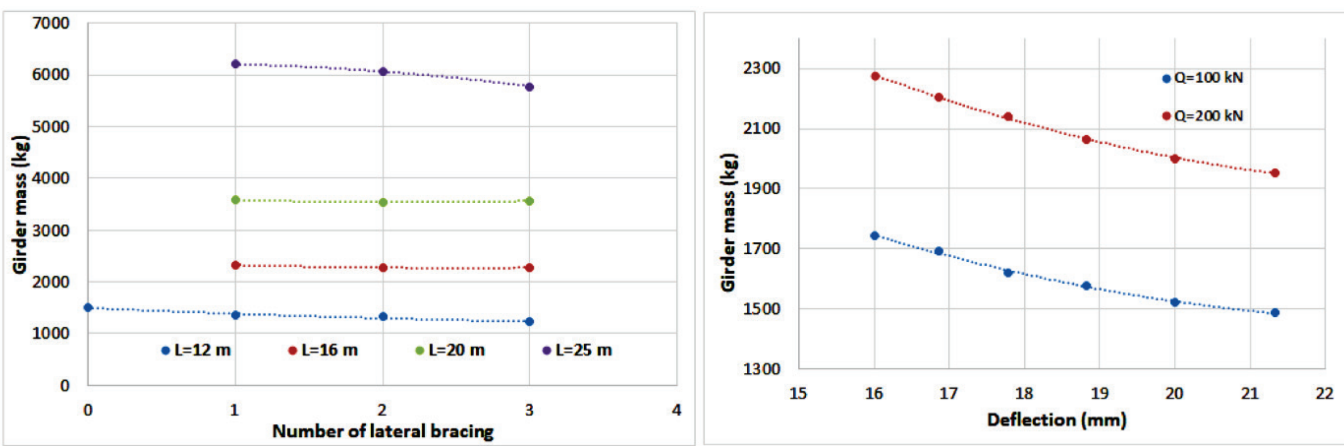

Figure 8 Mass of the girder; a) for different lengths of the girder and a different number of laterals bracing for the load of 200 kN, b) in correlation to the allowed deflection for a length of 16 m, the free length of torsional buckling of 4 m and the ratio of h/t = 120

Fig. 9a shows the optimal values of the mass of the girder for the lengths of 12 m and 16 m and the loads of 50, 100, 160, 200, 250 and 320 kN. These values of mass result from the structural optimization of the software *CATIA*. It is important to notice that the results obtained by the structural optimization in the *CATIA* module Product *Engineering Optimizer* are the same as the results obtained by the *SUMT* (*Sequential Unconstrained Minimization Technique*) method.

The h/t ratio also has an important effect on the mass of the girder. For the same length of the girder, the same free length of the torsional buckling and the same loads, a different mass can be obtained by changing the height and thickness of the web. An increase of the h/t ratio has a positive impact on the deflection of the girder, and the constraint for the allowed deflection was fulfilled faster.

Fig. 9b shows the correlation between the mass of the girder and the h/t ratio for the load of 200 kN, the allowed deflection $L/1000$ and the free length of the buckling of 4 m.

Girders with a high value of the h/t ratio have a problem because buckling can occur. It is necessary to check the girder for buckling and if necessary, to add an additional vertical and/or horizontal bracing on the web.

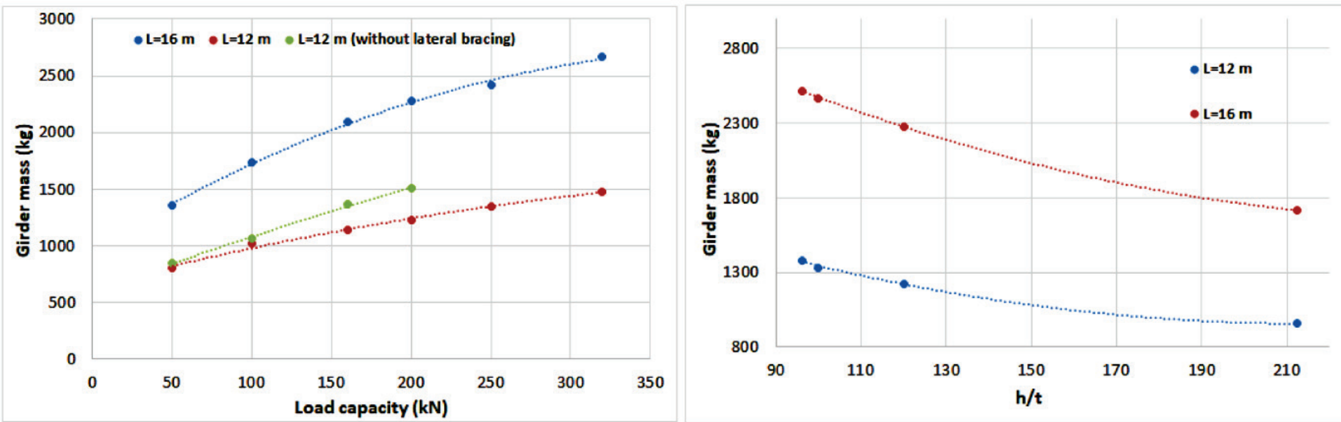

Figure 9 Mass of the girder; a) in correlation to the load of the crane for ratio $h/t = 120$ and free length of buckling of 4 m, b) in correlation to the ratio h/t for load of 200 kN, allowed deflection $L/1000$ and free length of buckling of 4 m

6 CONCLUSION

The goal of the optimization process carried out in this paper was to find the minimal value of the mass of the bridge crane girder designed as a welded I-profile. The mass of the girder depends on the input parameters such as the length of the girder, the load of the bridge crane, the allowed deflection and the ratio between the height and the thickness of the girder web. Optimization is carried out for different combinations of the above-mentioned input parameters.

For a numerical analysis and optimization, the *CAD/CAE* system *CATIA V5* was used. A structural numerical analysis is the first step that needed to be carried out to start with the optimization process. Using the structural numerical analysis data for displacements, the stresses and buckling coefficients can be obtained at all points of the design. With the help of computers and software, the calculation process is fast. Additionally, it is easy to control the values of all parameters and to obtain certain conclusions about the behaviour of the design for the applied constraints.

It is important to notice that for a successful optimization of the design, it is not enough to know how to work with computer software, but it is also very important to understand the real constraints of the design during exploitation. This knowledge is important if someone wants to develop an optimization model which is very similar to the real design. It is important to know how design is supported, where the loads are, how to implement some of the standards and recommendations based on experience. Every optimization model and optimization process have some errors, but it is important to minimize those errors and to develop such a model that is very close to the real one.

The *Product Engineering Optimizer* module in combination with the finite element method is a powerful tool which is easy to use and which gives a lot of useful data about the behavior of the design for different input parameters (dimensions, loads etc.). When using this module, it is possible to design lighter and more economical designs. Additionally, an important advance of this module lies in its fast calculation properties, which reduce the time of the design or redesign processes. The task which needs to be carried out by engineers is to develop an optimization model, run the calculation, and analyse the results. Engineers need to have some real life experience to precisely develop the optimization model and to analyse the results in the right manner.

A disadvantage of this module is the need to have computers with height characteristics, the so-called workstations. With workstations, it is possible to develop advance optimization models and to carry out calculations with a small amount of errors.

The optimization methodology developed in this research can be used for the optimization of similar designs. The mass of the girder can be additionally minimized by analysing others shapes of the girder cross section. For the results presented in this paper, it can be noticed that the material at the end of the girder is not used properly. It is possible to remove some of the material at those places of the girder. A girder can have a different height at the ends and at the middle.

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Preliminary communication

The Information – Communication Process in a Business with Outsourcing for the Maintenance of a Complex Technical System

Drago Kraljević, Krešimir Lacković, Robert Šojo

Abstract: This paper discusses the process of communication between service providers and recipients when monitoring and maintaining complex technical systems. This requires sophisticated equipment, trained personnel and special methods and procedures. This is especially true for technical diagnostics, as the most complex form of monitoring and preventive maintenance. The relevant elements of maintenance by state and the experience of engaging an external partner are highlighted, especially when the complete monitoring for process control is performed virtually. In that sense, an information and communication process is proposed to ensure the efficiency of the complete system. The education of the external partner and the connection with the holders of external memories, research institutions and centres of excellence can be emphasized.

Keywords: communication; information; maintenance; monitoring; process

1 INTRODUCTION

Technical systems, regardless of complexity, must be fully reliable in their operation. Additionally, there is a constant need to ensure reliability, and this is determined by the control and analysis of not only reliability, but also of economic efficiency. In this case, the starting point is to prevent the maintenance of complex technical systems. This applies to industrial plants with a high degree of technological equipment, but also to buildings of various uses that have a very complex management system.

In maintaining complex technical systems, a tendency towards perfection is necessary due to the fact that in such systems, any serious interruption of functioning can cause great economic damage, and can often cause human casualties. Therefore, highly educated personnel, appropriate equipment and methods or procedures are required in the maintenance of such facilities. One of the known methods of preventive maintenance of complex technical systems is technical diagnostics.

Given the accelerated development of techniques and technology, technical systems are becoming increasingly complex, which is why more sophisticated and expert maintenance methods and procedures need to be used accordingly. Since businesses usually do not have enough capacity or resources to monitor scientific advances in maintenance, an external partner can be hired for technical diagnostics. The problem of technical diagnostics becomes on the one hand a technical and on the other an economical cost. In such a situation, it is necessary to conclude analytically which variant is more favourable for the company. Moreover, it should be borne in mind that a complex technical system, if it is to function reliably and efficiently, must have all resources effectively allocated, and it is very difficult to believe that the company has sufficient capacity for technical diagnostics. The previous fact only confirms that the involvement of an external partner for monitoring and controlling the functioning of the system and technical diagnostics is a priority. An external partner usually has the resources at his disposal as it is his business activity and the assumption is that he has the human resources, resources and organization for a high level of productivity and quality. Furthermore, the external partner, in addition to the resources, can be linked to other research institutions, centres of excellence and expert teams. In addition to maintenance, the external partner can simultaneously control the business and technological process and thus constantly diagnose the functioning of each line or phase. With such monitoring, it is often possible to detect from a disturbance at some stage the cause that may be an indicator for a maintenance diagnostic or surgery procedure.

In the teaching part of this content, attention is given to defining the reliability of maintaining complex technical systems. The starting point of the review, along with process monitoring, is technical diagnostics as the most sophisticated and most professional form of maintenance prevention. Given that these are periodic, highly sophisticated operations, outsourcing as an organizational form of implementation is proposed, and the reasons for this approach are outlined. Accordingly, an information and communication system to successfully maintain the technical system with an external partner is proposed.

2 OUTSOURCING

Outsourcing can be defined as engaging an external partner to perform certain jobs for which there are no appropriate staffing, technical, or other conditions in an enterprise. The reasons for hiring an external partner may also be the fact that certain jobs will be done better but at a lower cost, because the foreign partner has better equipment and because of working methods. In the regulatory-legal sense, outsourcing is the contractual relationship for the transfer of some of the work or entire business activities to external partners, which in this way takes over one or more business activities of the company [1]. Outsourcing is therefore used to help an economic or public entity effectively perform its core and other activities in the best way while utilizing internal competencies, but at the same time to help mitigate the lack of skills and knowledge shortages in areas where the specialty of an external associate is sought [2].

In developed economies, outsourcing has established itself in the last twenty years as a business approach. In this respect, outsourcing has in particular included the following types of business:

- Website design
- Marketing and advertising
- Market research
- Development of mobile applications
- Financing and accounting
- Monitoring and control of the complete technological process.

In businesses and public establishments, the aforementioned jobs need to be supplemented by various types of ancillary work such as cleaning, keeping and maintaining the premises. Particular attention should be paid to the maintenance of complex building objects, machines, equipment, installations and IT hardware and software. Outsourcing has become not only a business approach, but also a philosophy that goes into multiple areas of work. Considering the stated, outsourcing also achieves the following effects [3]:

- Concentration on core business
- Expense reduction
- Availability of products and services at market prices
- Quality improvement
- Greater transparency of costs and services
- Avoiding employment risks and inefficiencies beyond the core business. Availability of modern techniques and technologies for maintaining systems without their own investment.

In addition to these reasons, outsourcing enables the availability of workforce over a contractual time period and has certain advantages, in particular [4]:

- Risk management because the external partner guarantees the quantity, quality and timing of individual jobs
- General efficiency because the outsourcer as a development professional applies all new methods, has more educated and ready personnel and means of work
- The external partner needs the constant development of employees.

Of course, there are some drawbacks in every business philosophy, which are especially the following [5]:

- There is a degree of threat to the security of confidential information if an external partner requires greater access to confidential information about the business of the company and parts of the production process
- To some extent, control over part of the business process performed by an external partner is lost
- Sometimes, the external partner cannot maintain the quality and standards of the business or production process
- By providing services to other clients (competitors), the external partner may come into conflict of interest at the expense of the recipient of the service
- A particular problem is if an external partner enters into a business relationship and comes under difficult business conditions (bankruptcy), when great material damage may occur, because the recipient of the service shares the fate of other bankruptcy creditors.

The main reasons for outsourcing in maintenance are [6]:

- Inexperienced own staff
- Outdated technologies
- Unforeseen hidden costs
- Loss of innovation capacity
- Insufficient experience in organizing and managing maintenance processes.

Outsourcing is a business activity because of its evident advantages such as quality, expertise, equipment, human resources, and labour productivity, and it has recently taken up increasing space in national economies. An increasing number of companies and public institutions, especially their subsidiary activities, are entrusting their external partner. It should be noted that the development of techniques and technology requires increasing efficiency on the one hand and a high level of expertise and quality on the other, which is why external cooperation is in some cases inevitable. This is especially true for the maintenance of complex technical systems, and especially necessary for technical diagnostics as the most complex part of preventive maintenance. All outsourcing companies, especially those that maintain technical systems, need to be extremely knowledgeable and equipped. Moreover, they must be able to take preventative action through the information technology. This means that they need to implement an appropriate information and communication system or process.

3 TECHNICAL MAINTENANCE

The results of successful outsourcing implementation are best exemplified by the maintenance of a complex technical system. In this case, this refers to the maintenance of complex building objects and sophisticated machinery and equipment, collectively called technical maintenance. In this case, maintenance is considered to be the procedures carried out preventively and in some cases through monitoring, and in the case of very complex equipment and particularly complex technical systems, technical diagnostics is performed as a special form of preventive maintenance. Furthermore, for some complex technical systems, it is necessary to constantly monitor the operation of complete technology. This means that the goal is to constantly monitor and determine the state of functioning of all lines and their production stages.

Maintenance through state monitoring is occasionally supplemented by a complex test or technical diagnostics. Maintenance of the equipment of high technological level systems and complex technical systems should be entrusted to an external partner because of certain advantages that have already been mentioned. This is primarily related to better technical equipment and better equipment for the human resources that the external associate has. Furthermore, the external partner ensures quality, deadlines and lower costs due to higher productivity.

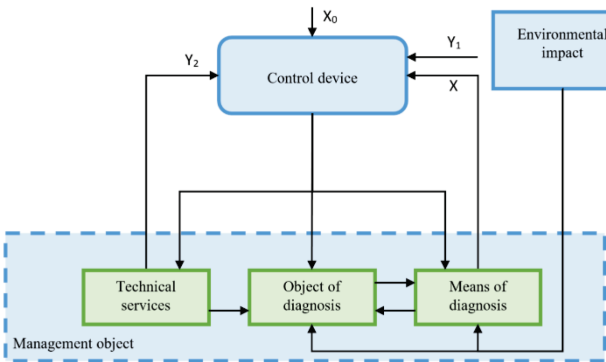

Figure 1 The basic process of technical diagnostics [7]

Technical diagnostics, as shown in Fig. 1, is an organizationally simple system but the methods, procedures, parameters, means and personnel, especially in complex technical systems, are often very complex. Therefore, a detailed description of the process depends on the complexity of the object and the diagnostic parameters and criteria. The maintenance of complex technical systems is a constant monitoring and determination of the condition, and also an undertaking of maintenance activities, i.e. this is actually constant technical diagnostics.

4 INFORMATION AND COMMUNICATION PROCESS

In the business of monitoring the technological process and maintaining it with the help of an external partner, especially technical diagnostics, it is necessary to build such an information and communication system so that the recipient of the service can be sure of the maintenance of his business or production system. An effective flow of information and communication between providers and recipients of services can be ensured with a well-organized information system enabled on the provider side. There are experiences and examples for this, such as the well-known CRM (Customer Relationship Management) or customer management [8].

The essence of CRM is that information technology is used to establish a permanent customer relationship. The starting point is one central unit on the service provider side that maintains constant wireless contact between clients and service providers. According to the source, it is actually a single contact centre that can be of lower and higher IT level. This contact centre provides a virtual connection with the recipients of the service. Fig. 2 shows one common contact centre, and it also shows that all information that is relevant and needed to clients is gathered in one place. Additionally, continuous feedback is provided to make communication effective. The provider may be informed of a need (especially an urgent one) at the right time and may act preventively.

The contact centre must be systematically linked to all essential functions of the service provider on the one hand and the customers on the other. This ensures an efficient service and enables immediate intervention when needed. Communication shall be ensured by information means, in particular:

- Different types of communication channels
- Web applications
- Business intelligence applications
- Internal ("background") business applications within the company itself
- Other forms of the Internet.

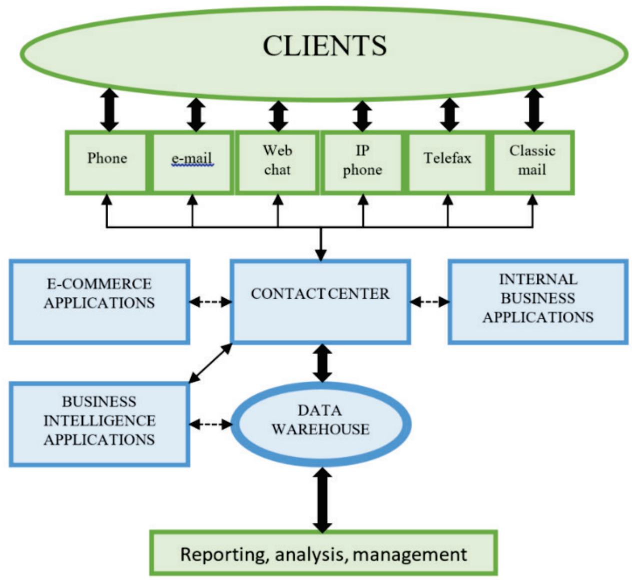

Figure 2 The basic process of technical diagnostics [9]

Regardless of the complexity of the service, the functions of the contact centre are in principle similar, regardless of the type of a technical system, as shown in Fig. 3.

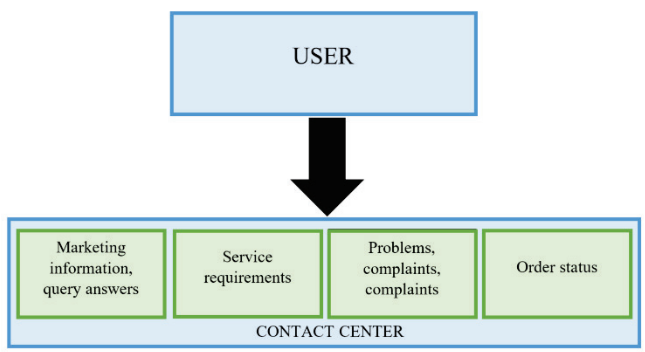

Figure 3 The basic process of technical diagnostics [10]

In the case of technical diagnostics, it is justified to use the proposed approaches as this ensures not only the diagnosis, but also the monitoring of the operation of the system after diagnostics.

Fig. 3 shows the functions or services that companies usually provide to their customers through the contact centre. In the early stages of the development of contact centres, these were all marketing information, requests for services and sending offers to customers as well as solving problems arising in mutual cooperation. The development of information technologies has enabled a dynamic two-way communication as shown in Fig. 7. Since the subject of consideration is technical diagnostics, just one complex sophisticated contact centre can provide efficient diagnostics of a complex technical system with high efficiency.

5 ARCHITECTURE OF THE INFORMATION-COMMUNICATION PROCESS IN MAINTAINING A COMPLEX TECHICAL SYSTEM BY OUTSOURCING

As it has already been mentioned, external partner services can be simple and very complex. In this case, the goal is to set up an integrated information and communication system to maintain a complex technical system through outsourcing. A complex technical system as a maintenance object implies a large number of stages and an even greater number of operations in certain stages of the process. A specific example of this can be found in larger automated manufacturing facilities, but also in complex construction objects of different uses. In any case, the goal is to maintain and control the process, to act preventively, and often to monitor the condition or functioning.

Certainly, in such systems, the technical diagnostics should especially be entrusted to an external partner, due to a number of afore-mentioned advantages. The efficiency of maintaining and operating a complex system can be ensured by defining and operating an appropriate information and communication system containing appropriate hardware and software.

Fig. 4 shows some production functions by individual stages where costs can be monitored in relation to the time course of production. Mathematically, from Eq. (1), this could be formulated as follows:

$$Y_5(t) = Y_1(t) + Y_2(t) + Y_3(t) + Y_4(t) \tag{1}$$

Eq. (1) is the production function of the process [11]. It shows the legality of the movement of costs over the duration of the process. An external partner can strictly control the process and provide management instructions.

Eq. (1) in conceptual terms represents a mathematical expression where $Y(t)$ represents the total costs of all three production lines and all four operations in the lines. Other labels such as $Y_1(t)$, $Y_2(t)$, $Y_3(t)$ and $Y_4(t)$ represent cost flows in individual production lines, which are the sums of the costs of individual stages in each line. In addition to monitoring costs by stages and production lines, it is possible to monitor product quantities, costs per product as well as profit per line, stage and product. The optimal production capacity as well as several indicators in the field of monitoring the condition and functioning of the technical system can be determined. Appropriate software should be installed for each of these types of monitoring in accordance with the mathematical expression.

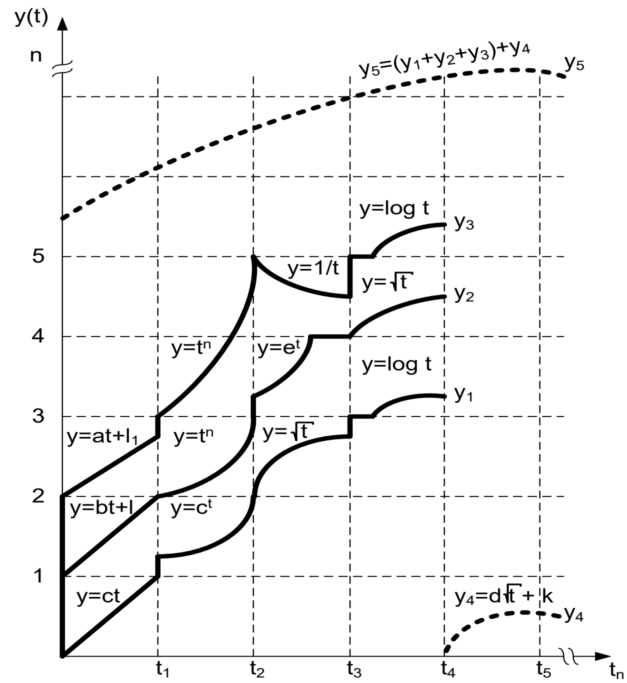

Figure 4 The basic process of technical diagnostics [12]

Fig. 4 shows one complex technical system with three production lines and four stages in each line. The technical system has lines and phases where the production function of that phase is shown at each stage. The production function shows the dependence of the movement of costs over time. Such an approach enables the mathematical simulation and monitoring of production, thereby setting the optimum combination of capacity utilization. In addition to the picture, the basic elements of collaboration, work execution standards, working methods, maintenance facilities and equipment, personnel and their experience and education must be elaborated. Fig. 4 also shows that the costs are summed up by the production stages and this must be all programmed in software. Furthermore, the complete business and maintenance process is monitored. The external partner has constant insight into the movement of the process, hence any deviation can be identified and the cause determined. For example, if unplanned costs occur at a certain stage, which can be caused by increased electricity consumption at that stage, this may be a problem in the rotational parts of a particular stage of production. Given the external partner's equipment, it is possible to provide immediate troubleshooting instructions. Moreover, costs are constantly monitored so that capacity can be adjusted to the optimal cost. When it comes to the technical diagnostics of the system, then there is a great deal of data to consider and prepare the system for more efficient and effective operation.

The complete process starts with the ordering of the business and ends with the result or benefits for the outsourcing service recipient. In order to maintain such a system, it is necessary to demonstrate the possession of adequate equipment as well as personnel who can perform complex tasks on the maintenance of technical systems. Furthermore, working methods to ensure productivity and quality are extremely important. Fig. 5 shows a management system that provides monitoring and operation with the support of appropriate hardware and software.

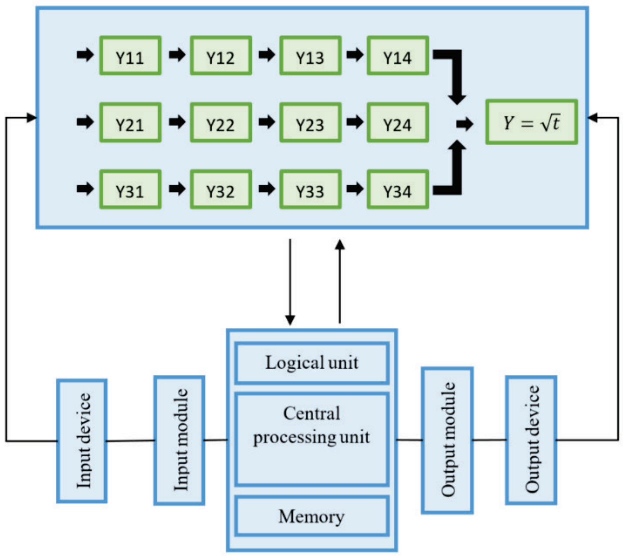

Figure 5 The basic process of technical diagnostics [13]

Appropriate hardware and software that will perform the monitoring function should be upgraded to this process, and the obtained data will be of great use for technical diagnostics. The development stage of information technology enables a wireless link between the maintenance provider and the technical system where partners have constant control over the functioning of the production and business process.

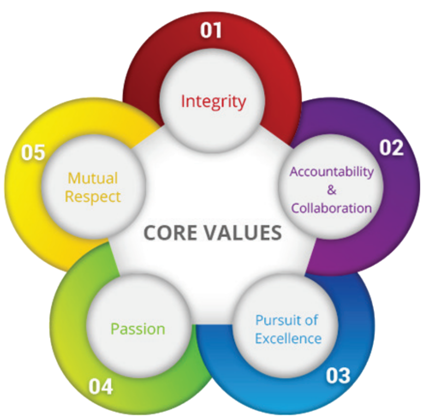

Figure 6 The basic process of technical diagnostics [14]

When the facility is a complex technical system, it is obvious that maintenance, especially technical diagnostics, should be performed by an external partner. That is why the external partner should be in constant contact, as any interruption of the system operation can cause high costs or losses. Moreover, an information and communication system is needed to support a permanent wireless link with the client. This creates a synergistic relationship in which the provider and the recipient of the service have several beneficial effects. Ideally, Fig. 6 shows a synergistic approach to the relationship between the client and the outsourcing service provider. The content of the picture shows that there is a synergy between the provider and the outsourcing service provider, which ensures the quality and efficiency of the service, as well as other benefits of common interest. This applies in particular to the development of the system and the tendency towards community, the pursuit of excellence, but a common interest also develops. As the picture suggests, more mutually beneficial values can be appreciated, which only confirms the possibility of long-term cooperation.

6 OUTSOURCING THE INFORMATION AND COMMUNICATION PROCESS WHEN MAINTAINING A COMPLEX TECHICAL SYSTEM

For convenience, Fig. 7 shows one integrated information and communication system where a maintenance system is connected to the management system. From it, you can see how an external partner is connected in the form of a contact centre where the flow of each operation in all lines of the production process is monitored. The very indication that the process is not proceeding according to the lawfulness of its production function warns that a problem is occurring and can be acted upon. In this regard, software may be set up so that, in accordance with the disturbance in the movement of the production function, it may suggest action to eliminate the problem. In particular, it should be noted that the service provider may be affiliated with research centres and expert teams. In this way, the external partner can effectively reach all the necessary information, but he may also have other necessary resources when needed.

A basic prerequisite for maintaining the state of a complex technical system is a secure connection and a particularly wireless (Internet) connection. Fig. 7 shows one possibility of a connection of an external partner with a complex technical system in which the connection between the system and the external partner is constantly made and the state or functioning of the technical system is monitored. It should be noted that the personnel at the service recipients have the opportunity to be informed about the functioning of the system, but are in constant connection with an external partner so that they can perform certain hardware and software interventions in case the condition control shows certain problems in the functioning.

The complete process will be successful if everything is well prepared with particularly appropriate hardware and software from the recipient, but fully coordinated with the service provider. Since in this example there is a virtual connection between the provider and the recipient of the service, the process must be able to permanently secure against any connectivity problem. Particular attention should be paid to the security of information activities regarding harmful external influences such as various types of viruses. An external partner can more easily provide the necessary programs with his experience and knowledge that eliminate attempts to introduce problems into the information and communication system.

The expert teams in Fig. 7 can also offer elements of business intelligence, which in this case is a way of delivering the right information in the right format to the right hands at the right time [15].

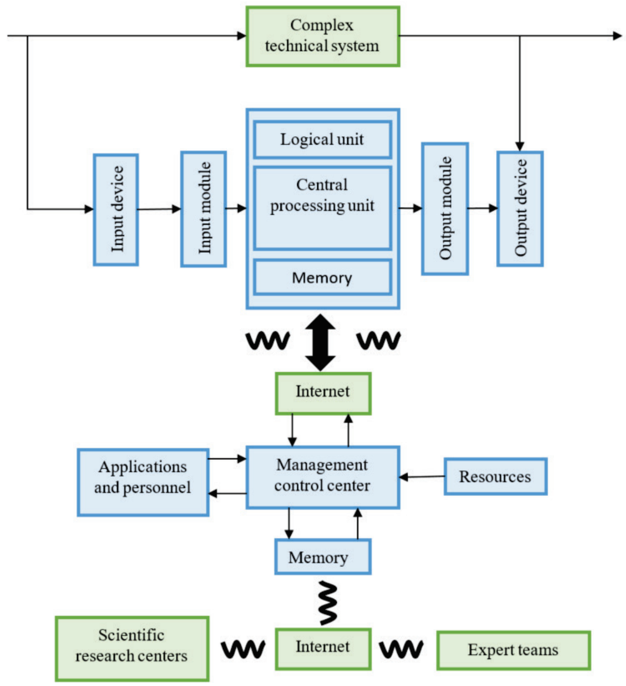

Figure 7 The basic process of technical diagnostics

Securing a virtual connection between the user and the provider can be addressed by the afore-mentioned CRM program. Moreover, with this or a similar software package, a permanent connection can be ensured between the service provider and some memory base, research or excellence centre.

According to the figure shown, the provider, unlike the recipient, usually has more educated staff, sophisticated equipment and a large memory base. Furthermore, the provider has a synergistic relationship with external memories, research centres and expert teams. This enables its high level of technology in terms of monitoring the state of production and functioning, and especially the maintenance of a complex technical system. The organization of the proposed approach ensures an extremely effective information and communication flow between the recipient and the provider.

Outsourcing can be continually refined in synergies between recipients and service providers and through the development of techniques and technology. In this respect, the outsourcing service provider, when maintaining complex technical systems, must consider the following factors [16]:

1. Customer satisfaction, which is the first and foremost factor
2. Measurability, which means that not only customer satisfaction is important, but also the ability to measure
3. Financial savings because for the client, this is the most important reason for outsourcing, in addition to quality
4. Sharing risks with a partner, which means that success and failure should be shared with the partner
5. The quality of the work done must be unquestionable and this is possible through continuous improvement of the provider in terms of new methods, resources and especially personnel
6. Consistency implies the continued availability of partner capacity according to the client's contractual requirements
7. Stability and diversity arising from the security of the contractual relationship, regardless of the changes caused by external influences
8. Predictability, which means that jobs, deadlines and other contractual clauses need to be precisely defined
9. The ability and expertise of the staff, which is possible through continuous training in a specific field of technical diagnostics
10. The speed and efficiency of responding to sudden needs as this avoids unnecessary costs and losses for clients.

Internet communication has other advantages such as the following [17]:

- 24-hour access to information
- Communication is interactive
- Clients are global; individual interaction is also possible
- It enhances dialogue while restricting communication.

The previous analysis of influential factors shows that in such complex processes, new methods and software should be explored. Moreover, achievements in the field of IT equipment should be monitored, as technological development can always offer even more modern solutions.

7 CONCLUSION

On the basis of analysing the previous text and illustrations, more conclusions can be drawn. First of all, the importance of state-of-the-art maintenance and technical diagnostics in complex technical systems is highlighted and documented. Maintaining such systems requires special staff and very complex equipment and operating methods and procedures. Moreover, and in particular for technical diagnostics, special time should be provided and staffing from regular production should be engaged, which creates additional costs with questionable labour productivity. Therefore, engaging an external partner is more effective, as this ensures quality and lower costs and greater system efficiency.

The paper presents examples of the information and communication connection when conducting business with external partners or outsourcing. In this regard, an information and communication process has been set up, and it should be monitored by appropriate hardware and software. In particular, it may be noted that an external partner can be associated with various external memory and research centres, which only increases its quality and reasons for engaging in the maintenance of a complex technical system.

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Preliminary communication

Energy Efficiency of a Wooden House

Anca Constantin

Abstract: An exemplary construction project developed in a commune close to Constanta, Romania, aims to build wooden houses for families with low income. The study focuses on their energy performance, aiming to determine simple technical solutions for the improvement of energy efficiency. The original house is a duplex ground floor building. The energy assessment was performed in accordance with the Romanian methodology for the original house, for the reference one and for a variant of the original house whose ground floor is insulated. The study showed that appropriate insulation of the ground floor which covers 30% of the thermal envelope area results in a heating energy saving of 17%. Furthermore, the original horizontal duplex was compared to its similar vertical version (ground floor and one storey) which is more compact, at the same heated volume and the same heated area. The reference vertical version saves 3% of heating energy.

Keywords: energy performance; heating energy; heat transmission; thermal resistance; wooden house

1 INTRODUCTION

The state of the art in the field of the energy performance of buildings brings in front of specialists the concept of smart sustainable buildings, encouraging an interweaved approach based on interior comfort, energy consumption and environment preservation. Besides these design principles, the Active House approach to buildings outlines the importance of the feedback from users [1]. Focusing on the inhabitants' wellbeing, the promoters of the Active House approach say that "today we have the technology and competences needed to build energy efficient buildings that positively affect our personal health" [1]. Unfortunately, the investment cost behind such a smart and energy efficient house is not affordable for the majority of people. Therefore, the engineers have to search for a cost-effective variant to build or rehabilitate a house, i.e. they have to obtain maximal possible energy efficiency and human comfort with minimal costs. This is the case of a generous project undertaken by the town hall of Cumpăna, in partnership with the Habitat for Humanity Cumpăna, that aims to build duplex ground floor houses for families in need [2]. Cumpăna is a commune close to Constanta, in the Dobrogea region, Romania.

Taking into consideration a low budget and a short building time, the houses have timber structure. They are sustainable, comfortable and affordable buildings. They are duplex ground floor houses and each includes two similar apartments. Wood-based panels are easy to work with and prefabricated elements are involved. Despite the fact that its compressive strength is similar to that of concrete, timber is used for low-rise structures. An important advantage, from the viewpoint of energy consumption, is that wood results in less thermal bridging than concrete or other construction materials. Moreover, the heat insulation performance of a 150 mm thick wooden wall is similar to that of a 610 mm thick brick wall [3]. However, wooden houses without thermal storage mass are more likely to overheat than brick houses [4]. Päätalo reconsiders a structure used in Middle Europe, namely an insulated double log wall, which provides a thermal transmission coefficient of 0.128 $W \cdot m^{-2} \cdot °C^{-1}$, for a 40 cm thickness made of two spruce log layers and with insulation between them [5].

In regions where there is a lack of wood, the wood-based panels are a cheap building material alternative. The thermal insulation properties of an oriented strand board and plywood-faced sandwich panels manufactured as wood-based structural insulation materials for walls and floors are very much appreciated. The thermal conductivity value of 0.12 $W \cdot m^{-1} \cdot °C^{-1}$ for an oriented strand board with the specific heat of 1500 $J \cdot kg^{-1} \cdot °C^{-1}$, at a temperature of 20.3 °C was reported by [6]. Later studies, such as [7], showed that the temperature influence on thermal conductivity manifested differently in transverse or in-plane direction for many types of panels. Less influence was reported in the case of the oriented strand board, for which the thermal conductivity was found to be of 0.275 $W \cdot m^{-1} \cdot °C^{-1}$ for in-plane direction and of 0.215 $W \cdot m^{-1} \cdot °C^{-1}$ for transverse direction, at a specific heat of 1552 $J \cdot kg^{-1} \cdot °C^{-1}$ [7].

Zehn [8] experimentally analysed the energy performance of a timber building placed in a cold region of China, and mentioned the rapid cooling of an uninhabited house as an accidental power failure occurs. They estimated the energy consumption of 24.61 $W \cdot m^{-2} \cdot year^{-1}$ for heating, as the wall thermal coefficient was 3.936 $°C \cdot m^2 \cdot W^{-1}$ at an indoor temperature of 20 °C [8]. The external temperature was not reported.

Moreover, the primary energy input in building materials is evaluated to be about 60–80% higher for concrete frames versus the wooden ones [9]. This assessment regarding the emissions was later confirmed by [10].

A high energy performance house can be achieved at a high investment cost, but the payback is usually rapid enough. When it comes to low-budget houses, not only low investment cost is important, but any effort to design the building as an energy efficient one must be taken into consideration.

The aim of our study is the energy performance assessment of a wooden house placed in a sunny and warm region of Romania, close to the Black Sea Coast. The study determines the difference in the heating energy consumption, primary energy and carbon dioxide footprint between the real house and the reference one and it also identifies the possibility of the energy efficiency improvement of the real house, taking into account a more compact version.

2 DESCRIPTION AND EMPLACEMENT OF THE WOODEN HOUSE

The new neighbourhood of Habitat houses is placed in the western part of Cumpăna. The first duplex houses have already been built, as it may be seen in Fig. 1.

Figure 1 Habitat houses in Cumpăna, left bottom corner of the picture (source: Google Maps)

Romania has five climatic regions. Cumpăna is situated on the Black Sea Coast, which is included in the first climatic region, characterized by a climate warmer than that in other regions. The yearly reduced temperature is 12.1 ℃ and the winter temperature for calculation is −12℃. The solar radiation has high intensity.

The depth of the groundwater was 10-12 m or even more. As the Black Sea-Danube canal was built close to this commune, the depth changed, in some areas the water rose to 5-6 m and in others it dropped to 15-16 m. Precipitations are low in this dry climate area.


Figure 2 Duplex house (the original horizontal duplex)

The houses are light timber structured with simple architecture, as in Fig. 2. They have two ground floor apartments and an attic. The foundations are continuous with simple concrete blocks and reinforced concrete elevations under the walls. The perimeter walls are 25 cm thick and the interior partitions have a thickness of 20 cm. They are made of wood-based panels with mineral wool in-between.

Each apartment is composed of a living room, two bedrooms, a kitchen and a bathroom. The duplex covers a rectangular area, 17 × 8 m, as it may be seen in Fig. 3.

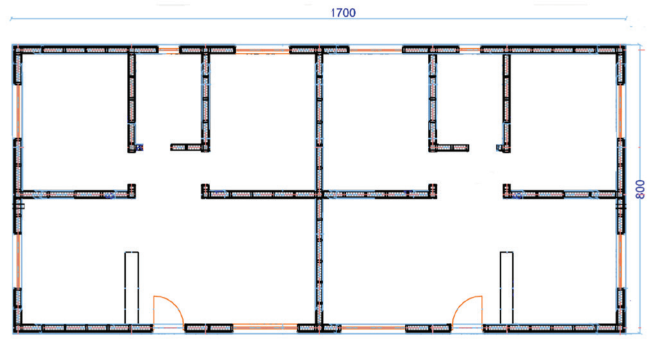

Figure 3 Ground floor layout

The walls have a good protection from fire and their thermal insulation is given through a thick layer of mineral wool.

3 METHODOLOGY OF THE ENERGY PERFORMANCE ASSESSMENT

3.1 Theoretical Considerations

The thermal energy transfer through a wall, which separates an indoor fluid medium of temperature θ_i from an outdoor fluid of temperature θ_e, depends on the thermal resistance of the wall, R (°C·m^2·W^{-1}). The thermal resistance is:

$$R = \frac{1}{\alpha_e} + \frac{\delta}{\lambda} + \frac{1}{\alpha'_i}, \tag{1}$$

where: i – index for indoor parameters; e – index for outdoor parameters; α_i, α_e – coefficients of the thermal convection of the internal and external surface of the wall, (W·m^{-2}·°C^{-1}); δ – thickness, (m); λ – coefficient of thermal conductivity, (W·m^{-2}·°C^{-1}).

Considering the stationary, the one-dimensional heat transfer through an infinite, homogenous one-layer wall, the thermal flux that passes through a normal area A, may be written as:

$$\dot{Q} = \frac{A}{R}\left(\theta_i - \theta_e\right) = L\left(\theta_i - \theta_e\right) \tag{2}$$

where L – thermal coupling coefficient, (W/°C).

Any layer added to the initial one introduces its own resistance, which is why the overall resistance of the multilayer wall depends not only on the thermal conductivity and thickness of each layer, but also on its orientation with respect to the heat flux [11]. As each construction element has finite dimensions and their ends are connected to other elements, thermal resistance is corrected, considering the more intense heat flux at joints, i.e. the thermal bridges.

Moreover, the external temperature is different for different elements of the envelope, which is why the coupling coefficient is also corrected.

The significant thermal capacity of the soil, associated with the random variation of the main climatic parameters, determines in fact a non-stationary character of heat transfer that generates both-way heat fluxes. The coupling coefficient for the ground floor is influenced by the presence of underground water.

The energy needed for heating a building is determined from a thermal balance equation, as the difference between the heat flux lost by conduction and convection through the building's thermal envelope and by air permeability of the walls, and the heat intake from the sun and from internal sources. The lost heat flux is written as:

$$\dot{Q} = H(\theta_i - \theta_e) \tag{3}$$

where: H – coefficient of total heat losses through the building's thermal envelope, (W·°C^{-1}).

The coefficient of total heat losses through the building's thermal envelope has two components:

$$H = H_T + H_V \tag{4}$$

where: H_T – coefficient of heat losses by conduction and convection, (W·°C^{-1}); H_V – coefficient of heat losses due to air permeability of the envelope, (W·°C^{-1}).

3.2 Methodology

The assessed house has three categories of energy consumption: for heating, for hot water preparation and for lightening. The house uses no regenerable energy sources. The heating system and the preparation of the hot water system use gas as a source of energy.

The study focuses on the heating energy consumption.

The ratio of the thermal envelope area over the heated volume is 1.18 m^{2}m^{-3}, higher than the limit of 0.7 m^{2}m^{-3} requested for an efficient, compact house.

According to the geometry of the house and the thermal properties of the materials that the envelope components are made of, the house coefficient of heat losses by transmission is H_T = 99.19 W·°C^{-1}, calculated with the coupling coefficients shown in Tab. 1.

Table 1 Thermal coupling coefficient of the envelope

Thermal envelope element		Area (m^2)	Corrected thermal resistance (°C·m^2/W)	Thermal coupling coefficient (W/°C)
Ground floor		126.16	2.04	29.80
Upper floor		126.16	2.51	24.17
Wall	windows	12.60	0.77	16.36
	N	17.68	3.28	5.39
	S	13.9	2.83	4.92
	E	40.58	4.25	9.55
	V	42.38	4.70	9.01

Considering a medium class of air permeability, H_V = 63.74 (W·°C^{-1}), the total coefficient is H = 162.93 (W·°C^{-1}).

The equilibrium external temperature, the one at which there is no heat flux through the building's envelope [12], results in θ_{ed} = 15.82 °C. Consequently, a 226 days heating period is obtained, as shown in Fig. 4, where the average temperature in each month, θ_{es}, is represented against the equilibrium temperature, θ_{ed}.

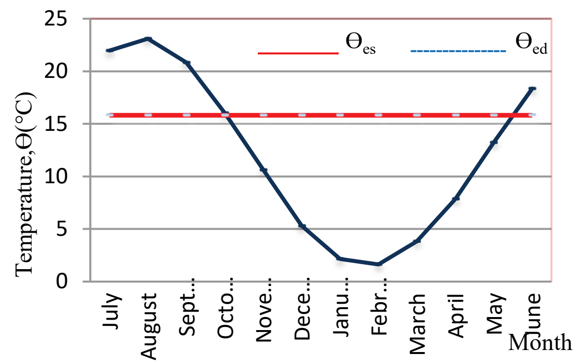

Figure 4 Heating period

The specific energy consumed for heating results in q_h = 71 kW·h·m^{-2}·year^{-1}. Looking at the thermal resistances in Tab. 1, one may notice a smaller value for the ground floor, which results in a higher dissipated thermal flux.

Adding the energy consumption for hot water preparation and for lightening, the total specific energy consumed for the house rises to q_h = 138 kW·h·m^{-2}·year^{-1}. The corresponding primary energy is E_p = 163 kg·m^{-2}·year^{-1} and the carbon dioxide footprint is E_{CO2} = 23 kg·m^{-2}·year^{-1}.

The same assessment was performed for the reference house, associated to the real one. The reference house is a virtual one, with the same geometry as the real house, but with high thermal resistance of the envelope (the minimal required values are stipulated by regulations [12]) and appropriate operation of the heating systems that result in minimal possible energy consumption. For the reference house, the total specific energy decreases to q_t = 104 kW·h·m^{-2}·year^{-1}, mainly due to the good thermal insulation of the ground floor.

Starting from this observation, a simple technical solution arises, which may improve the energy performance of the house: a cheap but efficient insulating layer on the ground floor. It significantly increased the corrected thermal resistance to 3.57 °C·m^2·W^{-1}. Even so, the thermal resistance of the floor is smaller than the recommended one, which is 4.5 °C·m^2·W^{-1} for new houses.

The same energy performance assessment was performed for the real house, considering the additional insulation of the ground floor. This is the case the study focuses on as an improvement technical solution (referred to as *solution* in Tab. 2 and Tab. 3). The investigations continue with the determination of the additional investment cost to insulate the ground floor, the payback period of time and the price of the saved energy. These indicators are needed to decide whether the proposed technical solution is appropriate from an economic point of view.

Subsequently, the same procedure was performed considering a similar version of the house, keeping the same heated volume, but with the two apartments placed one above the other. That means a vertical duplex, with half area of the ground floor, but the same heated area and the same heated volume. The house would become more compact, as the ratio of the thermal envelope area over the heated volume decreases to 0.9 m^2m^{-3}.

4 COMPARATIVE RESULTS REGARDING ENERGY PERFORMANCE

The energy performance assessment of the original house (horizontal duplex) was performed, following the same methodology, for the real house, the reference associated one and the real house with a simple solution for an improved performance. The results regarding the main technical indicators are gathered in the Tab. 2.

The first thing that draws attention when looking at the results in Tab. 2 is the big difference between the specific energy needed to heat the real house and the reference one. Despite the good thermal resistance of the walls and the upper floor, the weak thermal properties of the ground floor greatly influence the heat transmission coefficient. It is obvious that measures must be taken to decrease the heating energy consumption. The proposed solution, to add an insulation layer to the ground floor, seems to be appropriate since it decreases the heat transmission coefficient from 163 $W \cdot °C^{-1}$ to 145 $W \cdot °C^{-1}$. This solution results in the decreasing of the heating energy with about 17%. The overall energy saving is about 10 $kW \cdot h \cdot m^{-2} \cdot year^{-1}$.

Table 2 Energy performance indicators. Horizontal duplex

No	Indicator	U.M.	Real house	Reference house	Solution
1	Heat transmission coefficient	W/°C	163	118	145
2	Equilibrium external temperature	°C	15.82	14.23	15.30
3	Average external temperature (cold season)	°C	6.82	6.07	6.59
4	Heating period	day	226	206	219
5	Specific energy consumption for heating	kWh/m^2year	65	39	54
6	Total specific energy consumption	kWh/m^2year	138	104	128
7	Specific primary energy for heating	kg/m^2year	71	43	59
8	Total specific primary energy	kg/m^2year	163	135	151
9	Specific carbon dioxide footprint	kg/m^2year	23	20	21

Table 3 Energy performance indicators. Vertical duplex

No	Indicator	U.M.	Real house	Reference house	Solution
1	Heat transmission coefficient	W/°C	156	116	136
2	Equilibrium external temperature	°C	15.63	14.13	14.98
3	Average external temperature (cold season)	°C	6,82	6.07	6.59
4	Heating period	day	224	206	216
5	Specific energy consumption for heating	kWh/m^2year	61	38	49
6	Total specific energy consumption	kWh/m^2year	135	102	123
7	Specific primary energy for heating	kg/m^2year	67	41	54
8	Total specific primary energy	kg/m^2year	159	133	146
9	Specific carbon dioxide footprint	kg/m^2year	22	20	20

Speaking in terms of power per unit of area, the heating flux needed by the improved house is 30% of that mentioned by [5], and moreover, the reference house needs a much smaller amount to be heated.

The carbon dioxide footprint of the real house classifies it in the pollution class A+; therefore, the original house proves to be an environment friendly one.

However, the real house has a higher primary energy consumption that an nZEB one. It is imposed that an nZEB residence should have the primary energy consumption of $E_{p\ nZEB} = 98\ kg \cdot m^{-2} \cdot year^{-1}$. Therefore, it is rational to look for energy improvement solutions.

The energy efficiency assessment shows that the performance of the original house may be improved by insulating the ground floor. It is a simple and relatively cheap solution. Besides, other simple technical solutions may be taken into consideration, but their impact weighs less. Complex technical solutions may also be considered, but they are too expensive.

Referring to the proposed solution, the price of the saved energy is 0.05 $Euro \cdot kW \cdot h^{-1}$. The amount of the saved energy results in a payback period of about 7.4 years.

Taking into consideration the vertical duplex version of the house, a further improvement of the energy performance may be noticed. The same indicators as for the horizontal duplex were written in Tab. 3.

Comparing the data in Tab. 2 to the corresponding ones in Tab. 3, one may notice that the heating period during the cold season decreased by 2 days for the vertical duplex with no additional insulating layer (real house), and by 3 days for the improvement solution. The energy consumption for heating decreased by 6% for the real house and by 9% for the improvement solution.

5 CONCLUSIONS

Timber structured houses are a recommended choice for rapid building with a low budget. They are sustainable constructions and offer a comfortable and healthy ambiance for their inhabitants.

A house built for a low-income family must be conceived with aiming not only at a low investment cost, but also at the energy efficiency of the building.

The methodology used in this study relies on the heat balance in the thermal envelope of a wooden-made building, placed in a dry temperate climate region, with respect only to the heating energy. Further investigation regarding the cooling energy has to be performed as wooden houses with low thermal capacity may overheat during the summer.

The energy efficiency of the analysed wooden house could be improved by increasing the thermal resistance of the ground floor, the element that covers 30% of the envelope area. By increasing it with 70%, the heating energy decreases by 17%.

By insulating the concrete ground floor, the primary heating energy consumption decreases to E_p = 54 kg·m^{-2}·year^{-1}. Taking into account that the total primary energy requested for a nZEB is E_p = 98 kg·m^{-2}·year^{-1}, it results in the fact that the analysed house may be turned into a nZEB acting on two directions: by diminishing the energy for hot water preparation and by introducing regenerable energy sources. The emplacement of the houses and the appropriate insulation of the region make the photovoltaic panels very suitable for this purpose.

The vertical duplex version, with a smaller ratio of the thermal envelope area over the heated volume could have been a better choice for the wooden house. The reference house in the vertical version needs 3% less of heating energy than the horizontal one, for the same heated volume and the same heated area. Referring to the improved solution, the heating energy saving is up to 9% in the case of the vertical version.

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Notice

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Preliminary communication

Analysis of Methods for Determining Climate Loads at a Specified Territory Point by Meteorological Data

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Abstract: Methods for determining the characteristic values of climate loads at the location of a building have been perfected. Based on comparative analysis, the method of levelling the values of climate loads with an exponential or triangular weight function is recommended. For four climate loads, appropriate equalization intervals are determined, ensuring the maximum amount of weather data taken into account, while maintaining their uniformity. In construction, the determination of the climate load is important for the location of the building. When prescribing building standards, the values of the climate load are determined according to the data of weather stations in relative proximity, which provides values within the limits of reliability. Such an approach can lead to an overestimation of the characteristic values of climate loads and consequently increase the consumption of the construction materials of the building or, in the opposite case, decrease the unnecessarily high-energy consumption to condition the space inside the building.

Keywords: characteristic values; climate loads; load values at a given project point; meteorological data; territorial variability

1 INTRODUCTION

When designing load-bearing building structures, the calculated values of climatic loads are determined according to the norms [1, 2, 3]. As a rule, zone maps are given in norms, in which the territory of the country is divided into several regions with determined load values for the area of the region. When standards are prescribed, district load values are determined according to the data of individual weather stations in such a way that for certain parts of the region, they provide certain values within the confidence limits. In many cases, this leads to an overestimation of the characteristic values of climate loads and consequently an increase in the consumption of the construction materials of buildings.

A more accurate determination of the characteristic values of climate loads in the area of a certain construction site is possible on the basis of statistical processing of the results of meteorological observations, which is allowed by the norms [1]. Most often, samples of the annual maximums of the respective climatic parameters are used for this, which can be described by the Gumbel distribution [4]. The methodology of such calculations is described in [5, 6]. Determining the characteristic and design values of climate loads from actual meteorological data may in some cases lead to a reduction in the consumption of the building materials of newly designed buildings. Likewise, appropriate climate loads during the checking of the calculation of exploited structures may in some cases make it impossible to perform or reduce the laborious and costly work of reconstruction.

In the simplest case, the desired calculated climate load parameter is determined by the weather station located near the construction site. In the absence of such a weather station, data from several nearby weather stations are used, which can also increase the accuracy of the results by increasing the amount of the meteorological data used. Various methods for determining the estimated climate load parameters at a particular geographical point according to the local weather station network are outlined in [7, 8].

The purpose of this article is to improve and comparatively analyse different methods for determining the characteristic values of climate loads at a particular geographical point according to the data of the local network of weather stations.

2 PRELIMINARY ANNOTATION

This article analyses methods for determining the characteristic values of climatic loads at a specific point in the territory (hereinafter referred to as the project point) according to the data of weather stations in the region. The problem is solved by the example of meteorological observations in the territory of Ukraine. For the study, a meteorological database has been formed for 172 flat weather stations, the network of which quite fully and evenly covers the territory of Ukraine. When forming the database, information was used [9, 10], which shows the sample sizes of annual maximums, their mean values and standards, as well as the characteristic values of the loads corresponding to the generally accepted repetition period T = 50 years. The duration of the observation is generally 25 to 50 years, with only 70 cases out of 688 using shorter series of 10 to 25 years.

The used meteorological data have a stochastic nature, which determines their random variability in time and space. In addition, there are some changes of load values due to the influence of geographical and climatic factors. Differences in the periods of meteorological observations at different weather stations increase the heterogeneity of these data. Therefore, the methods that are used for the evaluation of the loads at a given point of the territory should provide verification of the uniformity of the data of meteorological stations.

For each weather station, latitude and longitude in degrees, altitude in meters and the statistical characteristics and characteristic values of four climate loads are known:

snow cover weight, ice weight, maximum wind pressure and wind pressure with ice. For each load, the number of observation years, the average value of the sample of the annual maxima, the standard of the annual maxima sample, and the characteristic value of the load are given in the database.

Statistical characteristics of the snow cover weight on the earth's surface were obtained by processing samples of the annual maximum snow cover weights formed according to [9]. Average values and norms for the ice weight, maximum wind pressure, and wind pressure with ice were taken from [10]. Characteristic values are calculated in [9, 10] by the formula

$$Q_0 = M + 2.6S \tag{1}$$

based on the description of the annual maximums' pattern by the Gumbel distribution law [4, 5] with an average value of M and a standard of S, and what is also taken into account is the average repetition period of the characteristic load value $T = 50$ years. The approximate formula (1) gives results that are quite close to the exact values [4, 5].

The meteorological database described below is used for the comparative analysis of the methods for determining characteristic values of climatic loads at a specific geographical point according to the data from a local weather station network.

3 METHODS FOR DETERMINING THE CLIMATE LOAD AT A PROJECT POINT

3.1 Definition based on the Actual Data of a Particular Weather Station

The simplest way to get a characteristic load value from real-time weather data is to directly use the observation results at a weather station located close enough to a specific project point. Due to this, it is necessary to create a sample of the annual maximums of the appropriate climate load and to perform its statistical processing. The characteristic value is calculated using the approximate formula (1) or its more exact versions given in [4, 5]. Such a method can give false results due to accidental observation errors or the influence of the mesoclimatic characteristics of the weather station used. In addition, this method is not generally applicable in the absence of a weather station in the immediate vicinity of the project point, as it happens in most cases of site selection.

3.2 Combining Data from nearby Weather Stations

To obtain more reliable and accurate results, it is necessary to use data from several weather stations near the project point. The accuracy of the results is increased by increasing the amount of the meteorological data used, and the reliability is increased by averaging the mesoclimate characteristics of several nearby weather stations. Generalized results thus characterize a particular area along the area of the project point.

Observation results on weather stations L are shown by known sample sizes N_k, their average values of M_k and variance $D_k (k = 1, \dots L)$. Differences in the available data may be due to random fluctuations in the results of observations at neighboring weather stations, as well as due to regular differences in climatic characteristics. Therefore, to make the decision to combine the data from a selected group of weather stations, it is advisable to use a one-way variance analysis [11].

The classic formulation of the analysis of variance with respect to the comparison of the data of several weather stations can be formulated on the basis of [11]. We consider L weather stations closest to the project point with the numbers $k = 1, \dots L$, for each of them there are samples of different contents of N_k meteorological observations X_{ki}, $i = 1, \dots N_k$. The possibility of combining all available data into one common sample should be checked.

$$N = \sum_{k=1}^{L} N_k \tag{2}$$

To do this, average values and variances are calculated for each sample compared.

$$\begin{aligned} M_k &= \frac{1}{N_k} \sum_{i=1}^{N_k} X_{ki} \\ D_k &= \frac{1}{N_k - 1} \sum_{i=1}^{N_k} \left(X_{ki} - M_k \right)^2 \end{aligned} \tag{3}$$

The average value of the combined sample is

$$M = \frac{1}{N} \sum_{k=1}^{L} \sum_{i=1}^{N_k} X_{ki} \tag{4}$$

Within-group variation, which on average characterizes the random spread of data within a single weather station, is calculated

$$D_{\mathrm{wg}} = \frac{\sum_{k=1}^{L} D_k \left(N_k - 1 \right)}{\left(N - L \right)} \tag{5}$$

Between-group variation, which depicts the scattering of data between weather stations and thus characterizes the influence of the deciding factor (specific weather station) on the total variance of the combined sample, is calculated

$$D_{\mathrm{bg}} = \frac{\sum_{k=1}^{L} N_k \left(M_k - M \right)^2}{\left(L - 1 \right)} \tag{6}$$

The statistics of the Fisher's variation comparison criterion are calculated by the formula

$$F = \frac{D_{\text{bg}}}{D_{\text{wg}}} \tag{7}$$

and it compares with the critical value of the Fisher's F_{cr} (k_{bg}, k_{wg}) statistics from the F-distribution tables for the selected significance level (usually α = 0.05 or α = 0.01) and the number of the degrees of freedom $k_{\text{bg}} = L - 1$ and $k_{\text{wg}} = N - L$. If $F > F_{\text{cr}}$ is obtained, a second set of weather stations near the project point should be selected and the calculation repeated by using the above algorithms.

For $F \le F_{\text{cr}}$, the data samples of all L weather stations can be considered homogeneous. They need to be combined into a total volume sample (2) and statistically processed. The desired characteristic value of the test load at the project point is determined by the formula (1) or its more accurate analogous data based on the Gumbel distribution, taking into account the statistical characteristics of the combined sample.

The second variant of the task of combining data from the nearest weather stations assumes the absence of the patterns of observation results, which are represented by the known values of N_k, mean values of M_k and variants of D_k, k = 1...L. For these purposes, the analysis of the variance procedure modified by the authors is used. The total volume of the combined sample N is determined by the expression (2) and its average value is calculated by the formula

$$M = \frac{\sum_{k=1}^{L} M_k N_k}{N} \tag{8}$$

The within-group variation D_{wg} (5) and between-group variation D_{bg} are calculated by the formula (6). The statistics of the Fisher criterion (7) are compared with the critical value $F_{\text{cr}}(k_{\text{bg}}, k_{\text{wg}})$ for the selected level of meaning and the number of the degrees of freedom $k_{\text{bg}} = L - 1$ and $k_{\text{wg}} = N - L$.

For $F > F_{\text{cr}}$, it is necessary to reduce the number of weather stations closest to the project point in order to obtain $F \le F_{\text{cr}}$. In this case, the data of all L weather stations can be considered homogeneous and combined into the total distribution of meteorological observations (2), whose mathematical expectations are equal to (8), and the variance is calculated by the formula

$$D = \frac{D_{\text{wg}}\left(N - L\right) + D_{\text{bg}}\left(L - 1\right)}{N - 1} \tag{9}$$

The presence of the statistical characteristics (8) and (9) allows us to determine the desired characteristic load value at the project point according to the formula (1) or a more accurate formula.

For the more reliable determination of the characteristic value of the load at the project point, it is advisable to use the largest possible number of weather stations closest to it and, accordingly, a large set of initial meteorological data. The analysis of variance should begin at all weather stations located within a radius of about 100 km from the project point. For $F > F_{\text{cr}}$, the outermost weather stations should be removed from this set to obtain $F \le F_{\text{cr}}$, which allows the data of all recorded weather stations to be combined into a single sample or into a common distribution.

3.3 In-Plane Interpolation Method

The method proposed in [10] for determining the calculated climate load parameters at a given point in the territory (project point) is based on the use of a plane that connects the value of the desired parameter to the three nearest weather stations. The characteristic value of the load at the project point Q is determined from the equation of the plane passing through the characteristic values of this load Q_1, Q_2, Q_3 at the three nearest weather stations. The weather stations that form the interpolation triangle are selected by the decision of the designer or researcher based on the minimum distance from the project point and their orographic area so that the project point is usually located within the interpolation area. Experience shows that for the same project point, several different interpolation triangles can be selected.

After transforming formulas [10] from a local coordinate system into a global one, we obtain the desired value of the characteristic value of the climate load at the project point with the coordinates x, y.

$$z = \frac{D}{C} - \frac{A}{C}x - \frac{B}{C}y \tag{10}$$

The coefficients of the formula (10) are determined by the coordinates x_i, y_i and the characteristic load values z_i for the three stations that form the interpolation triangle:

$$\begin{aligned}
A &= (y_1 z_2 + y_2 z_3 + y_3 z_1 - y_3 z_2 - y_2 z_1 - y_1 z_3) \\
B &= (x_2 z_1 + x_3 z_2 + x_1 z_3 - x_2 z_3 - x_3 z_1 - x_1 z_2) \\
C &= (x_1 y_2 + x_2 y_3 + x_3 y_1 - x_3 y_2 - x_1 y_3 - x_2 y_1) \\
D &= (x_1 y_2 z_3 + x_2 y_3 z_1 + x_3 y_1 z_2 - x_3 y_2 z_1 - x_2 y_1 z_3 - x_1 y_3 z_2)
\end{aligned} \tag{11}$$

To perform the calculation in a spread sheet, it is enough to enter the coordinates of the project point and select the interpolation triangle, after which the calculations are automatically performed according to the formulas (10), (11). The position of all weather stations and the project point can be set both in latitude and longitude in degrees, as well as in the selected rectangular coordinate system.

In order to analyse the stability of the described method, the examples of determining the characteristic values of the snow cover S_0, maximum wind pressure W_0, ice weight G_0 and wind pressure with ice $W_{0\text{G}}$ for five project points located in different regions of Ukraine were considered (such cities as Kropyvnytskyi, Lviv, Nizhyn, Kharkiv, and Kherson). A local network of 9 ... 10 weather stations located at a distance of 120 km from the project point was used. From these weather stations, 10 different interpolation triangles were formed, from which the characteristic values were calculated by using (10). As an example, Tab. 1 shows the results for the city of Kropyvnytskyi.

Tab. 1 shows that the results of calculations using different interpolation triangles have an unacceptably large spread. The mean value of the 10 options gives more stable results, approaching the values of certain weather station data in Kropyvnytskyi. For other project points, qualitatively close results were obtained, which together indicate a significant dependence on a sufficiently subjective choice of the interpolation triangle.

Table 1 Variability of characteristic load values in Kropyvnytskyi, calculated using 10 different interpolation triangles

Characteristic load values	S_0 (Pa)	W_0 (Pa)	G_0 (N/m)	W_{0G} (Pa)
the smallest of 10 options	1161.9	306.4	10.5	186.3
the highest of 10 options	1348.6	394.4	22.5	236.5
the average of 10 options	1248.3	356.1	16.4	213.4
Meteorological data for Kropyvnytskyi	1210.6	350.0	13.7	210.0

In order to increase the stability of the results, some authors proposed to modify the considered method for determining the characteristic values of climatic loads by plane interpolation. The improvement is that the possibility of using interpolation triangles is checked by using the above mentioned analysis of variance, and the final result is determined by the average of the results of multiple interpolation triangles.

3.4 Method of the Equalization of Characteristic Values

Changes in the characteristic values by a territory can be represented as an unstable random field [5, 11] represented by a surface of mathematical expectation showing regular climatic changes of the load in the territory and a random component due to the geographical characteristics of individual weather stations and measurement errors. Levelling this field with a weight function, which reduces the importance of weather stations as they move away from the project point, allows for the alignment of random components and thus the detection of regular load changes in the study area. The levelling process can be considered as a modification of the method described above for combining the data from a network of weather stations, taking into account the reduction of the role of weather stations as it moves away from the project point. In this paper, the levelling method [5] is improved by taking into account the sample sizes from which the characteristic values of the climate load and the mathematical justification of the levelling interval values are determined based on variance analysis.

Taking into account the methodology described above to evaluate the possibility of combining the data from neighbouring weather stations by using variance analysis, a modification of the data levelling technique [5] has been developed, which is described by the following algorithm (12) to determine the characteristic value of the climate load at a given project point. The initial data are the characteristic values of the load Q_k and the sample size N_k, according to which they are determined for all L weather stations in the territory. The dispersions of characteristic values are estimated using the approximate formula obtained in (12):

$$D_{Qk} = \frac{0.36\, Q_{0k}^2}{N} \tag{12}$$

For each of the L weather stations, a weight function is calculated that takes into account the distance d_k from the weather station with the number k to the project point, according to one of the formulas:

$$C_k = \exp\left(-\frac{d_k}{a}\right) \tag{13}$$

$$C_k = 1 - \frac{d_k}{a} \text{ when } d_k < a \qquad C_k = 0 \text{ when } d_k \geq a \tag{14}$$

Where a is the levelling interval, expressed in the units of distance.

The equivalent observation volume N_{ek} for the k^{th} weather station and the total equivalent observation volume, which determine the characteristic value at the project point, are:

$$N_{ek} = C_k \times N_k \qquad N_e = \sum_{k=1}^{L} N_{ek} \tag{15}$$

The characteristic value of the load at the project point is:

$$Q = \sum_{k=1}^{L} \frac{N_{ek} \times Q_k}{N_e} \tag{16}$$

The within-group and between-group variation for determining the F-criteria are calculated using the formulas:

$$D_{wg} = \sum_{k=1}^{L} \frac{N_{ek} \times D_k}{N_e} \qquad D_{bg} = \sum_{k=1}^{L} \frac{N_{ek}\left(Q_k - Q\right)^2}{L} \tag{17}$$

The observed value of the Fisher criterion statistics $F = D_{bg}/D_{wg}$ is compared with the critical value $F_{cr}(k_{bg}, k_{wg})$ for the selected level of significance and with the number of the degrees of freedom, depending on the equivalent number of weather stations and the data taken into account.

For small values of the levelling interval, when considering the small amount of meteorological data, the Fisher criterion statistics do not exceed the critical value: $F < F_{cr}$. The increase in the levelling interval leads to an increase in between the group variance. Until $F > F_{cr}$ occurs, indicating that it is impossible to combine the selected meteorological data. The longest levelling interval is optimal, at which the condition $F \leq F_{cr}$ is fulfilled, thus ensuring that the maximum possible amount of temporal data is used while maintaining their uniformity.

In order to select the best type of the weight function (13) or (14) and to determine the optimal value of the levelling interval according to the described methodology, the calculation was performed for each of the four climate loads at five project points located in the cities of Kropyvnytskyi, Lviv, Nizhyn, Kharkiv and Kherson. Variance analysis was performed at the significance levels of $\alpha = 0.05$ and $\alpha = 0.01$. The levelling intervals gradually increased until $F > F_{cr}$ was obtained, which allowed their optimal values to be identified for each load type at each of the five project points.

The results of the calculations showed the closeness of the characteristic load values obtained on the basis of the exponential (13) and triangular (14) weight functions. The difference between them does not exceed ± 3%. Therefore, for practical use, we can recommend the weight functions (8) and (9) with the levelling intervals given in Tab. 2.

Table 2 Recommended levelling intervals values

	Levelling intervals (km) in formulas	
	(13)	(14)
Weight of snow cover	50 - 55	130 - 150
Maximum wind pressure	30 - 35	70 - 80
Weight of ice	15 - 25	40 - 70
Wind pressure with ice	40 - 45	110 - 120

The levelling intervals listed in Tab. 2 are obtained by summing the calculation results for the five project points.

The smaller values of the levelling intervals correspond to a significance level of 0.05 and the large ones to 0.01. The lowest levelling interval values were obtained for the weight of the ice and the highest for the snow load. The analysis showed a tendency of the narrowing of the levelling area with increasing territorial variability of loading. The deviation of the levelling interval from the optimal value in Tab. 2 within 10 ... 20% changes the result by 1 ... 2%.

In general, the results of the analysis showed that for practical use in load normalization for the territory of Ukraine it is possible to recommend an exponential (13) or triangular (14) weight function with levelling intervals from Tab. 2. The desired characteristic load value at a given project point is calculated by (16) considering equivalent amounts of data (15) and one of the weighting functions (13) or (14) without conducting the variance analysis. To determine the characteristic values of the load at the project points of other territories, it is necessary to first clarify the optimal values of the levelling intervals listed in Tab. 2 by performing the variance analysis by using the method described above.

4 COMPARISON OF THE ACCURACY OF THE CALCULATION METHOD

In order to select the best method for the considered determination of the climate loads at a given project point, the characteristic value of four climate loads for the five project points located in the cities of Kropyvnytskyi, Lviv, Nizhyn, Kharkiv and Kherson is compared. The characteristic values for each project point are determined by the methods described above:

1) According to the actual data of the weather station located at the project point;

2) Combining the characteristics of the samples of the annual maximum loads according to the results of the variance analysis;

3) Plane interpolations by selecting interpolation triangles according to the results of the analysis of variance and the average of several results;

4) Equalization of characteristic load values with an exponential weight function (13);

5) Levelling of characteristic load values with a triangular weight function (14).

As a result of the calculation, 100 characteristic values were obtained, the analysis of which allowed us to evaluate the accuracy of these calculation methods. The problem of benchmarking the methods used to determine the characteristic load values at a particular project point is the lack of fully reliable benchmarks with which to compare results. Using the calculation results based on actual meteorological data obtained at the project point (method 1) as a benchmark is incorrect, as the data of an individual weather station may have some random deviations due to the measurement errors and mesoclimatic characteristics of each weather station. Therefore, the used characteristic values are averaged over all five methods. The percentages of deviations of the characteristic values determined for each of the five methods from these averages are analysed, and the average percentage modules of the deviations for all project points are shown in Tab. 3. The logic behind such an analysis is that the closeness of the results obtained by different calculation methods indicates the reliability of these methods.

Table 3 Average modules of the percentage deviation of characteristic values, calculated by different methods

Method for determining the characteristic value	Percentages of the deviation of characteristic values				
	S_0	W_0	G_0	W_{0G}	Average
According to the weather station at the project point	11.59	11.92	14.68	8.67	11.72
Combined numerical characteristics of samples	9.21	8.78	21.33	7.25	11.64
Plane interpolation average results	4.73	8.91	16.51	6.44	9.15
Levelling with an exponential weight function	2.69	2.63	8.78	2.01	4.03
Levelling with a triangular weight function	3.18	3.01	9.01	2.76	4.49

It can be seen from Tab. 3 that the largest deviations for the ice weight load are obtained. For the remaining loads, approximately the same percentage deviations are obtained. The general accuracy characteristic of the method of calculating characteristic values is the percentage of deviations for individual loads, as well as their average values indicated in the last column of Tab. 3. Based on these data, it can be concluded that the calculations by the first two methods for determining the characteristic values of the load at a given project point have the least accurate results. The third method (plane interpolation with the average of the results of several interpolation triangles) provides slightly smaller deviations of characteristic values, but it also has an excessively high complexity due to the need to "manually" select several interpolation triangles, perform the variance analysis and average the results. The mutual convergence of the characteristic load values obtained by these methods indicates sufficient accuracy and reliability of the results.

Therefore, methods 4 and 5 are recommended for practical use, based on the levelling of the characteristic load values with an exponential (13) or triangular (14) weight function, which provide sufficiently high accuracy in determining the characteristic values at a given project point.

5 CONCLUSIONS ON THE RESULTS OF THE RESEARCH

1. Based on the meteorological data from 172 weather stations in Ukraine on the snow cover weight, maximum wind pressure, ice weight and wind pressure with ice, the known methods have been improved and new methods have been developed to determine the characteristic values of the climate loads at a given project point.

2. Formulas have been obtained for a one-way variance analysis, which allows one to decide on the possibility of combining the statistical characteristics of the annual maximum loads in the absence of samples themselves.

3. Based on benchmarking, the methods based on the levelling of characteristic load values with an exponential or triangular weight function are recommended for practical use, which give the highest accuracy of all results.

4. Appropriate levelling interval values for four climatic loads have been established to ensure that the maximum amount of weather data is taken into account, provided that they are homogeneous. The deviation of the levelling interval from the recommended values by 10 - 20% changes the result by 1 - 2%.

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Preliminary communication

Industry 4.0 Readiness Assessment: Comparison of Tools and Introduction of New Tool for SME

Bernhard Axmann*, Harmoko Harmoko

Abstract: This research aims to establish an assessment tool for assessing the readiness of small and medium enterprises (SME) in industry 4.0. The assessment of the current and future status is crucial for companies to decide on the right strategy and actions on the road to a digital company. First will be compared existing tools such as: IMPULS (VDMA), PwC and Uni-Warwick. On that basis, a tool for SME will be introduce. The tool has 12 categories: data sharing, data storage, data quality, data processing, product design and development, smart material planning, smart production, smart maintenance, smart logistic, IT security, machines readiness and communication between machines. Those categories are grouped into three: data, software and hardware. Each category has five levels of readiness (from 1 to 5), with particular criteria that refer to literature studies and expert's opinion.

Keywords: data exchange; digitalization; hardware; Industry 4.0; SMEs; software

1 INTRODUCTION

In last past years, several assessment tools have been created by researchers from university, consultant company, and government institution. The tools can help companies to measure, how ready they are in facing industry 4.0. Each assessment tool has different dimensions of measurement, it depends on the focus and object of research. In this paper, three existing assessment tools (IMPULS, Uni-Warwick, and PwC tools) will be reviewed, and used as basis for establishing new assessment tool which more focus on Small Medium Enterprise (SME). The selection of SMEs, is encouraged by the fact that SMEs as engine growth of global economic, have lack understanding about industry 4.0. With the new assessment tool, SME can assess their current position and determine next step or future target in industry 4.0.

2 LITERATURE REVIEW

2.1 Small Medium Enterprises

Many studies have explained that SMEs play an important role in national economy, they have employed many people and become the engine growth of economic [1], [2], [3]. The definition of SMEs is diverse for each country, the European Commission defines small medium enterprises (SMEs) as company which employ less than 250 employees and have turnover up to 50 million/year [2]. While in Germany, SMEs are defined as companies that have less than 500 employees [4].

The SME is characterized by limited resources (skilled workers, infrastructure and budget), however the flexibility of decision making is relative easier and faster compared to large companies, because the bureaucratic path is short and relies on few people.

2.2 Industry 4.0 and Its Benefit

The fourth industrial revolution or I4.0 was first initiated by a group of business people, academics and German government in 2011. By definition, Industry 4.0 is the collective strategy of company which equip their business process, especially production process with digitalization, internet of thinking, cyber physical systems (CPS), and smart factory to present real time synchronization of business and production flows [5]. However, this definition is not the only one, there are still multiple of definitions and none of them are used as common references [6].

The application of Industry 4.0 has three main goals: shortening time to market, increasing flexibility, and boost efficiency [7], [8]. With achievement those goals, the benefits of I4.0 can be felt by company as well as national economy. In Germany, the adoption of I4.0 has increased 25% of company's efficiency and contribute around 1% / year to Gross Domestic Product (GDP) over 10 years as well as create 390,000 new jobs [9].

3 RESEARCH METHODOLOGY

This research leads to two objectives: comparing the existing tool and establishing a new tool which focus on SMEs. Before comparing existing tools, the author will determine the most relevant categories / dimensions for SMEs. The tool that assess those categories will be scored as (1). While, the tools that do not assess them, will be scored as (0). After all the tools have been scored, the sum of score (each tool) will be divided by the number of relevant categories/dimensions (see Eq. (1)). The tool which has highest assessment index AI (Tool 3) is the most suitable tool for measuring SMEs readiness in industry 4.0 (see Tab. 1 as illustration).

$$Assessment\ Index = \frac{\sum Score\ of\ Tool}{Number\ of\ Relevant\ Categories} \qquad (1)$$

In order to provide a complete picture of the existing tools, the author conducts a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis for each tool. With

SWOT analysis, the "internal" strength and weakness and the "external" market driven opportunities and threats of each tool will be made transparent. This is important as a basis for establishing new assessment tool.

Table 1 The illustration of comparison method

Category	Tool 1	Tool 2	Tool 3
Category A	1	0	1
Category B	1	1	1
Category C	0	0	1
∑ Weight	**2**	**1**	**3**
Assessment Index	**0,67**	**0,33**	**1**

Table 2 The illustration of SWOT analysis

Strengths (internal) *What the focus of Tool* *What the unique thing, that available*	**Weaknesses (internal)** *What must be improved* *What common thing, that not available*
Opportunities (external) *How can the strengths of tool turn into opportunities*	**Threats (external)** *What threats could harm the tool*

4 RELEVANT CATEGORIES FOR SME

In establishing a new assessment tool that focuses on SMEs, it is necessary to determine relevant categories that can measure the I4.0 readiness appropriately. The determination of categories must be objective and supported by sufficient arguments. Those can be obtained by literature study, expert opinion, and field observations.

Similar to the house construction, the implementation of industry 4.0 must be supported by at least three readiness pillars, namely: Data, Hardware, and Software. Therefore, the categories of I4.0 readiness will be clustered by those three.

4.1 Data

The company data can be likened as blood in the human body. It must be protected and able to flow smoothly. Therefore, all blockages and constriction that interrupt the data flow must be removed immediately. Otherwise, it will disturb the entire business process and gradually destroy company's reputation. The "**Data**" cluster can be divided into 4 categories: Data sharing, Data Quality; Data Processing and Data Storing.

The use of data as basis for company decision-making process, becomes more intense in the digitalization era (I4.0). The data has become a valuable commodity [10], where many companies hang their fate on data availability. A data must have good quality. The quality of data can be measured by 15 dimensions: accessibility, ease of maintenance, reputation, accuracy, objectivity, credibility, comprehensiveness, constituent interpretability, consistent representation, clarity, relevance, reasonable scope, completeness, value added and timeliness [6], [11].

The intensity of sharing, processing and storing data does not depend on the size of company, but it depends on number of stakeholders which involved to company. Sometimes small and mid-sized companies are more active than larger companies. In the context of security, data sharing activity always brings risk, it becomes hacker`s way to attack the system, therefore data sharing management is absolute necessary for securing system [12].

4.2 Software & Process

Digitalization is the key word in industry 4.0, without digitalization in business processes (product development, production, logistic and others), the company will never turn on industrial 4.0. The digitalization in SMEs will bring some beneficial functions, such as; overcoming fluctuated customer`s demand, smoothing internal and external information flow, accelerating decision making processes and others [13]. Therefore, digital transformation on SMEs is necessary and it must be supported by software that appropriate to requirements and budget of company. In the product development, SMEs are encouraged to use software that is not focused on Product Data Management (PDM) only, but also on Product Lifecycle management (PLM), where the life cycle of a product, from its birth until it is recycled or destroyed, must be well managed.

The second pillar (Software & Process) consists of categories: product design & development, smart material supply, smart production, smart maintenance, and smart logistics. These categories reflect the processes in SMEs that require software support. The software will increase the added value and competitiveness of products through process efficiency.

4.3 Hardware

The biggest obstacle to apply Industry 4.0 in SMEs is unpreparedness hardware (computer, machines, robot, server, and material handling) and IT security, because every replacement and modification of hardware and IT security system require high investment cost. Therefore, those are important parameters for measuring SMEs readiness in Industry 4.0.

Hardware readiness, not only measured by their compatibility, but also the interface and communication infrastructure between them. For example, hardware can be ready individually, but when it is paired to the other or integrated into company system, the hardware will have problems. Therefore, the third pillar will consist of categories: hardware readiness, communication between hardware and how to secure information and data placed in hardware from unauthorized person, hacker and external infiltration (IT Security and Data protection). Data protection and IT security especially for electronic transactions must be a serious concern for SMEs. The use of hardware and software that supports digital signatures, biometric data, ledgers (hardware wallet), smart contracts and block chain technology, must be balanced with the needs and financial capabilities of SMEs [14, 15].

5 OVERVIEWS OF THE EXISTING TOOLS

5.1 IMPULS (VDMA)

In 2015, VDMA sponsored a study to build assessment tool for measuring German company's readiness toward industry 4.0, the assessment tool is designed with simple, user-friendly and effective principles that allow companies to conduct by their self.

The IMPULS's tool measures six dimensions, namely: strategy and organization, smart factory, smart operations, smart-products, data-driven services, and employees. Each dimension has several sub-dimensions, which explain detail measuring. The company's readiness will be explained by six levels, it is started from level 0 to 5. The level 0 is called outsider, where company does not apply digitalization at all. The level one is beginner level, where the company start to digitalize their business process and adopt industry 4.0 principles. The next levels are: level 2 intermediate, level 3 experienced, level 4 expert, and level 5 top performer, where industry 4.0 is already unified with company's culture [16].

5.2 Uni-Warwick

This assessment tool was developed by Warwick University in collaboration with Crimson & Co and Pinsent Masons. The main objective of this tool development is to provide a simple and intuitive way for companies to measure their readiness as well as their future ambitions in digitalization era.

There are six dimensions of measurement which include; products and services, manufacturing and operations, strategy and organization, supply chain, business model and legal considerations. What's interesting about this tool is, there are special dimensions which never encountered in other assessment tools. Those dimensions are supply chain and legal consideration. In the supply chain there are 4 sub-dimensions, namely; inventory control using real-time data management, supply chain integration, supply chain visibility, supply chain flexibility and lead times. While, in the legal consideration dimension, there are 4 sub dimensions, namely; contracting models, risk, intellectual property and data protection. Unlike the IMPULS's tool, each dimension of Warwick's tool is measured by 4 levels of readiness, namely level 1 beginner, level 2 intermediate, level 3 experience and level 4 expert [17].

5.3 PricewaterhouseCoopers PwC

PwC views the assessment tool that they built is not only as a tool to assess the readiness of company but also as the future planning anchor, toward industry 4.0. The tool consists of 7 dimensions: Digital business models and customer access; Digitisation of product and service offerings; Digitisation and integration of vertical and horizontal value chains; Data and analytics as core capability; Agile IT architecture; Compliance, security, legal and tax; and Organisation employees and digital culture. Each dimension consists of four levels readiness, start from digital novice, vertical integrator, horizontal collaborator, and digital champion.

The unique point of PwC tool is, there is dimension of compliance, security, legal and tax. This dimension measures company compliance in facing the challenges of digitalization, such as security, legal, and taxation. The readiest company in industry 4.0, is the company that most comply to various regulations of I4.0 such as data protection, taxation and other legal aspects [18].

6 THE COMPARISON OF EXISTING TOOLS

Before comparing the existing tools, it should be emphasized that, this section is not intended to find the best tool, but to provide references for new assessment tool creation, which focused on SMEs.

The SWOT analysis (Tab. 3) shows that IMPULS tool is superior in the number of dimensions and categories that relevant to SMEs, while PwC can present the more attractive graphic or design of online self-assessment.

Table 3 SWOT analysis

IMPULS (VDMA)	
Strengths	+ Available Online self-assessment https://www.industrie40-readiness.de/?lang=en + Description of dimensions / categories and its level are clear and understandable + Many dimensions / categories that are relevant for SMEs + Proven to survey around 200 companies in Germany + The questions in online assessment are clear
Weaknesses	– Presentation of online-assessment is clear, simple but not as interesting as the PwC tool – Dimensions and categories are too focused on the manufacturing industry.
Opportunities	Higher possibility to be used by SMEs through measuring relevant dimensions
Threats	Open Online assessments can affect survey statistics (if a survey is conducted)
PwC	
Strengths	+ Available Online self-assessment https://i40-self-assessment.pwc.de/i40/interview/ + The presentation of on-line assessment is clear, simple and eye-catching + The questions in online assessment are clear + Proven to survey 2000 companies in 26 countries
Weaknesses	– Description of dimensions / categories and its level difficult to understand – Complicated for SMEs, due to many irrelevant sub-dimensions' measurement – Dimensions and categories are too focused on the digital business.
Opportunities	The possibility to be used by SMEs through measuring relevant dimensions
Threats	Open Online assessments can affect survey statistics (if a survey is conducted)
Uni-Warwick	
Strengths	+ Measuring the company readiness with a broadly dimensions (Products and services, Manufacturing and operations, Strategy and organisation, Supply chain, Business model and Legal considerations) + Description of dimension and its level are clear and understandable + Proven to survey 53 companies in 22 countries
Weaknesses	– Not available online self-assessment – Complicated for SMEs, due to many irrelevant sub-dimensions' measurement
Opportunities	The possibility to be used by SMEs through measuring relevant dimensions
Threats	The company's reluctance to use this tool, due to difficulty of self-assessment (not available online)

Uni-Warwick tool can capture many readiness aspects of the company, which reflected in many measurement dimensions / categories. However, the consequences of it, makes Uni-Warwick tool, look complicated. In addition, Uni-Warwick tool is not available in open access online, so companies must judge and calculate the result manually, based on the description of each level in each dimension. All the facts above can make Uni-Warwick tool less attractive then other assessment tool.

From the comparison above it can be seen that the measurement dimensions in the IMPULS tool are most appropriate for measuring the readiness of SMEs in Industry 4.0, this is indicated by the high value of assessment index. This fact is reasonable, considering the economic and industrial structures of Germany which dominated by SMEs, may also influences the perspective of IMPULS tool creator in determining dimensions and categories

Based on the comparison and SWOT analysis, the new assessment tool must meet the requirements:

- The tool must be able to measure SME readiness in industry 4.0, through the relevant categories.
- The tool must be accompanied by a practical guideline which contains different readiness levels
- The categories and their levels must be defined properly, so that companies are able to know their current status and future step in I4.0.
- The description of each category and each level must be clear and understandable.
- The assessment tool must available online to facilitate companies in conducting self-assessment.
- The presentation of online assessment must be clear and eye-catching.
- The questions in online assessment must be clear, simple and understandable

By considering those requirements, the new assessment tool is created with categories and readiness level as level as seen on Tab. 4.

Table 4 Comparison tools with relevant categories for mid-size company

Category	IMPULS (VDMA)	PwC	Warwick
Data			
Data sharing	1	0	0
Data Quality	1	0	1
Data Processing	1	1	1
Data Storage	1	0	1
Software			
Product development	1	1	1
Smart Material supply	0	0	1
Smart Production	1	1	1
Smart Maintenance	0	0	0
Smart Logistic	1	1	1
IT Security	1	1	1
Hardware			
Hardware readiness	1	0	0
HMI or M2M Interface	1	1	1
∑ Weight	**10**	**6**	**9**
Assessment Index	**0,833**	**0,5**	**0,75**

Table 5 New assessment tool

Categories		Level	Description
Data	Data quality	I	No Activity
		II	Clear Responsibility
		III	Effort known + Benefit analysed
		IV	KPI (Key Performance Indicator) defined
		V	Continuous Improvement for Data
	Data sharing	I	No Data sharing
		II	Data is exchanged between the individual devices within the department
		III	The machines and computers in the company can communicate with each other without barrier
		IV	Company-wide sharing (across locations)
		V	Cross-company use (between companies)
	Data processing	I	No Activity
		II	Define standard data format The effort and benefit for all report are known, The biggest waste and idle time are known Selection of processes & data for automation (RPA)
		III	Define "lead software" for data input Determine primary system for data analysis Identification the relevant signal process Selection of Robotic Process Automation (RPA) software
		IV	Define central data storage Create instructions and rules for data entry Optimization the signal process Analysis and description of processes and data flow to implement RPA
		V	Open access for all software to central data storage Continuous improvement of data processing (reporting + production process) Application of RPA
	Data storage	I	The data is stored in the respective machine or PC
		II	The data is stored on the server of the local department
		III	The data is stored on the company server
		IV	Simple cloud technology for data storage
		V	Advanced and optimized use of cloud technology for storage
Software	Product design and development	I	The software is only used to create 2D drawings or 3D models on CAD
		II	Additional technical calculations, simulations and analyses are carried out using software.
		III	Implementation of automated cost calculation software and the use of 3D printing to speed up testing, trial and decision-making
		IV	Integration software and implementation of product data management (PDM) and product lifecycle management (PLM)
		V	The use of Digital Twin technology for the development of complex products
	Smart material planning	I	Start to develop material planning
		II	Applying the refill strategy and MRP software for material planning
		III	Optimization of delivery planning by evaluating the KPIs of suppliers
		IV	the automation of administrative processes in material planning by RPA
		V	Connecting material planning with suppliers
	Smart production	I	Planning is not done by Excel (not special software)
		II	Use of PPS (production planning and control) software but not integrated yet to other software
		III	Creating an interface between CAD and PPS, defining data standards and applying lean principles to avoid waste

Table 5 New assessment tool (continuation)

Categories			Level	Description
Software			IV	Introduction of production data acquisition with MES and SCADA software
			V	Integrate PPS system into the ERP system
	Smart maintenance		I	Start to develop of manual maintenance planning
			II	Identification of critical components
			III	The using of sensors for monitoring critical components and introduction of KPI
			IV	The using of software to evaluate sensor data and for maintenance planning (predictive maintenance)
			V	Connecting the maintenance software with the ERP software
	Smart logistic		I	Traditional logistics system
			II	Use of Microsoft Office for a simple logistics system
			III	Introduction of route planning and a logistics information system
			IV	KPI evaluation and optimization of the logistics system
			V	Excellent logistics system with state-of-the-art IT (e.g. 5G network) and complete automation (AGVs, electric floor conveyors and automated high-bay warehouses)
Hardware	Machines readiness		I	Know critical process parameters
			II	Know the status of the control and sensors of the machines
			III	Sensors and control (hardware) for process optimization available for individual machines
			IV	Sensors and control (hardware) for process optimization available on all machines
			V	Hardware (machines, robots and computers) for process optimization with AI available
	Machine communication		I	The machines do not communicate at all
			II	Individual machines are networked together or via a central computer
			III	The use of Object linking and Embedding (OLE) for process control
			IV	The application of Open Platform Communications (OPC UA)
			V	All machines are networked with each other and OPC UA has been introduced across the board
	IT security		I	Password & user-name
			II	Initiate exchange information and add device´s ID for accessing
			III	Encryption and Decryption the exchanged data
			IV	Data security and digital transaction efficiency through Digital Signature, Biometric data, Ledger (hardware wallet), Smart Contract and Block Chain technology
			V	Continuous monitoring & Security Analytic

7 CONCLUSIONS

The present three assessment tools (IMPULS, PwC and Uni-Warwick) can be used to measure a company's readiness towards industry 4.0, but none of them focuses on SMEs. If the three are compared, the IMPULs tool is the nearest appropriate assessment tool for SMEs, because it contains many dimensions or categories that are relevant and needed by SMEs such as; data sharing, data storage, data quality, data processing, product design and development, smart material planning, smart production, smart maintenance, IT security, hardware readiness and hardware interface.

Establishing an assessment tools for SMEs, must meet requirements such as; the tool must contain relevant categories and accompanied by a practical guideline, the categories and levels must be defined and described clear and understandable, the tool must be available online with eye catching presentation and simple questions.

Notice

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Preliminary communication

Additive Manufacturing of Polymer Moulds for Small-Batch Injection Moulding

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Abstract: In case of small-batch production, applications of classic technologies and tools, for e.g. injection moulding and classic moulds are not competitive. Application of additive technologies (AT) for direct production of finally parts can partially reduce deficiencies of classic approach, but there are for e.g. limited number of available materials. Potential solution is application of AT in production of so called bridge moulds for small-batch production from originally requested material for final part. This paper presents *PolyJet* process of AT and its possible application for production of bridge polymer moulds for injection moulding of small quantity of the moulded parts together with design rules for *PolyJet* bridge moulds.

Keywords: 3D printing; design rules; *PolyJet* polymer moulds; small-batch injection moulding

1 INTRODUCTION

Modern markets define increased demands on development and production processes. Besides demands on increased product quality, flexibility level in development and production processes, at the same time there are demands on decreasing costs and specially on reducing time for development and production. An additional trend, as a part of megatrends linked with global increasing of human population, and which is highlighted in some segments of global market, is abandoning of mass production and transition to small-batch or even one piece (personalised, custom) production, leading to changes in production paradigm [1]. For fulfilling such demands on the market, since 1980's additive production (3D printing) processes are in constant development. Main characteristic of this processes is adding material mostly layer-by-layer until production of the final product, based only upon 3D CAD product models, without any need for additional tools (like in case of subtractive or forming processes). Such principle enables production of products with very complex geometrical shapes, which will be very difficult or even impossible to produce by the application of classic technologies. However, despite mentioned advantages, additive manufacturing has certain disadvantages, compared to the classic technologies. First of them, is the limited range of available materials appropriate for additive manufacturing, compared to for example with injection moulding of polymers. Moreover, the physics of making products layer-by-layer is significantly different from physics of classic processes (e.g. injection moulding), resulting in deviations from the expected mechanical and other properties of the products made by additive and classic production processes. In case, when it is necessary to produce certain product in a small series for testing of future products, or for product certification, such deviations are not permissible. For the utilisation of additive manufacturing advantages, possible solution of the mentioned problems can be found in the application of additive manufacturing for production of so-called bridge moulds (tools), which enable production of small series products from original materials with original production processes (e.g. injection moulding). The paper presents *PolyJet* process of production bridge moulds, specificity of their production and advantages of their application in practise.

2 SYSTEMATISATION OF 3D PRINTED MOULDS

The demands on moulds for serial production by injection moulding and the possibilities of additive manufacturing processes are not completely in compliance, therefore direct application of additive manufacturing for injection moulding in the industrial environments still does not have the expected significance despite invested efforts in this field [2, 3]. Rapid Tooling (RT) processes are exposed to far sharper demands compared to Rapid Prototyping (RP) processes. In case of RT processes, produced moulds must stand long-term parameters of e.g. injection moulding (pressures, temperatures, impact loads, shear loads, etc.), they have to be wear resistant, they have to be produced in very narrow tolerances with high surface quality for moulded part aesthetics and for easier moulded part ejection from the mould cavity.

When durability of the moulds (mould inserts) for injection moulding becomes important, 3D printed moulds are divided into three groups:

- soft (temporary) tools/moulds,
- bridge tools/moulds,
- hard tools/moulds.

In case of *soft moulds*, only a few moulded parts can be produced within such moulds, before the moulds are worn or damaged. An example of this type of moulds is a silicone mould (Fig. 1). The main advantage of this tooling approach is that such moulds can be produced within one day.

A small-batch production of dozen to a few thousand parts can be run with so-called *bridge moulds* (Fig. 2). Final number of produced moulded parts depends on applied materials (paper, metal, polymers ...). Bridge moulds also can be produced in relatively short time (from one to few days), which also depends on applied materials and additive technologies.

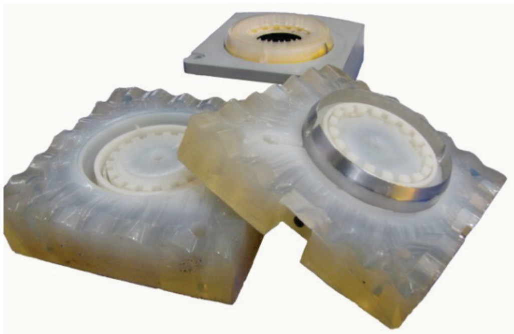

Figure 1 Soft (silicone) mould [4]

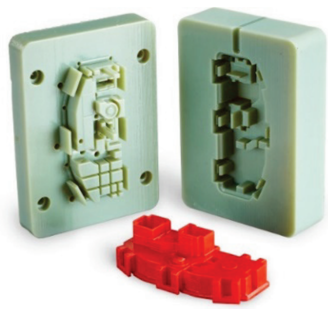

Figure 2 Bridge (*PolyJet*) mould [5]

Finally, with *hard moulds* (Fig. 3) it is possible to produce a few hundred thousand moulded parts. Their durability is similar to the moulds produces in conventional ways, but they require much more time and expenses for production, compared to the soft and bridge moulds.

Figure 3 Hard metal mould insert [6]

3 *PolyJet* ADDITIVE TECHNOLOGY

According to the standard ISO/ASTM 52900 [7], all processes of Additive Manufacturing are divided into 7 categories: binder jetting, direct energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photo-polymerisation. The *PolyJet* process belongs to the material jetting processes of additive manufacturing. Generally, the *PolyJet* process consists of jetting a thin layer of photosensitive polymer material(s) (acrylic resins) in the form of fine droplets through a head with a nozzle grid, followed by curing with a source of UV light (UV lamp) (Fig. 4).

In the return path of the printing head, a small cutter will remove small bulging at the top of the layer which results in spreading the material in the form of droplets, obtaining a more accurate layer thickness.

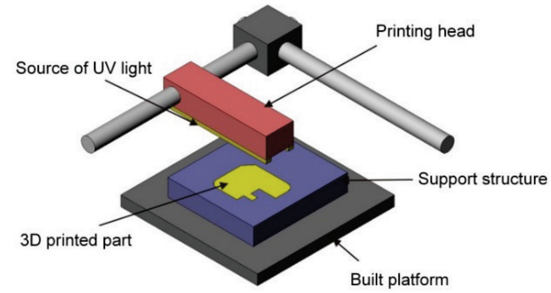

Figure 4 *PolyJet* process principle [1, 2]

The layer thickness can be set to 16 μm or 32 μm. While jetting one layer, during the production complex parts, the 3D printer uses both, model and support materials [1] (Fig. 5).

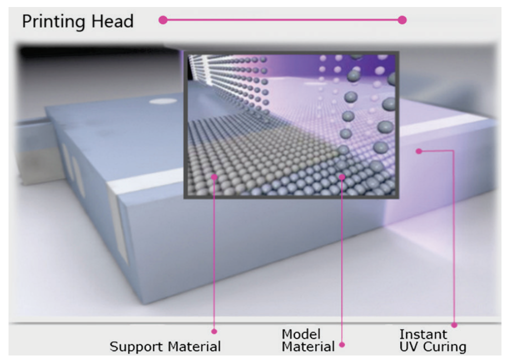

Figure 5 *PolyJet* process - Printing of built and support material [2]

After finishing one layer, the build platform is lowered down for next layer thickness and the process is repeated until finishing the part. After removing the finished part from the build platform, the support material should be removed from the finished 3D printed part (e.g. with water jetting).

The main advantage of the *PolyJet* process is the ability to cure the whole layer at the same time, which is much faster compared to some processes that use selective curing on the working layer (e.g. like Stereolithography). The *PolyJet* process is very accurate, and as it uses model materials in liquid form, a small surface roughness can be achieved. Therefore demands for additional treatment of *PolyJet* 3D printed parts are minimal. Also, as each layer is fully cured during the printing process, there is no need for additional curing after 3D printing [1]. Second generation of *PolyJet* printers enabled application of two different types of basic acrylic resins as built materials at the same time in a process called *PolyJet* Matrix. The *PolyJet* Matrix process works by simultaneously jetting two distinct photopolymer built materials in pre-set combinations (previously prepared and separated in the STL file). The dual-jet process combines these materials to produce multi-material parts and create new composite materials, called Digital Materials [8].

3.1 *PolyJet* Technology for Production of Temporary/Bridge Moulds

PolyJet moulds for injection moulding are not intended to be a replacement for soft or hard tools used in mid- and high volume production. Instead, they are intended to fill the gap between soft and hard moulds as well as a substitute for 3D printed prototypes [1].

In cases where design changes are required, a new iteration of the mould can be created in-house at minimal cost. This, combined with the speed of the *PolyJet* 3D printing, allows designers and engineers greater design freedom. Complex geometries of moulded parts and moulds do not represent any limitation in *PolyJet* mould manufacturing. Moreover, for this process NC programming is not needed, and manufacturing is based only on mould CAD model [1].

Fig. 6 shows a comparison of moulds produced with *PolyJet* technology and moulds produced with classic technologies from common mould materials and AM technologies for production of metal bridge/hard moulds. It has to be stressed that A and B processed materials (e.g. unreinforced polyolefins) are far less aggressive, and C and D groups are more aggressive materials for mould cavity wall wearing (e.g. reinforced polymers) [9].

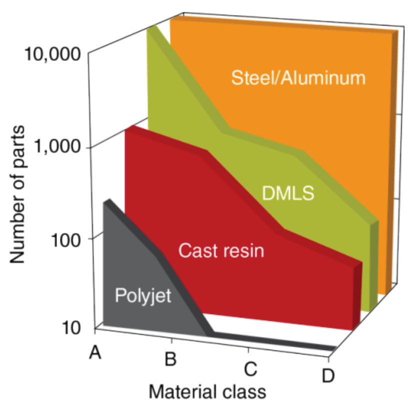

Figure 6 Anticipated number of produced parts depending on the type of the mould and material class [9]

Some of typical polymer materials which can be processed in *PolyJet* moulds regarding Fig.6 are:

A Polyethylene (PE)
Polypropylene (PP)
Polystyrene (PS)
Acrylonitrile Butadiene Styrene (ABS)
Thermoplastic elastomer (TPE)

B Fiber glass filled Polyproylene (PP+G)
Acetal (Polyoxymethylene - POM)
Polycarbonate-ABS blend (PC+ABS)

C Polycarbonate (PC)
Fiber glass filled Acetal (POM+G)
Polyamide (PA)

D Fiber glass filled Polycarbonate (PC+G)
Fiber glass filled Polyamide (PA+G)
Polyphenylene Oxide (PPO)
Polyphenylene Sulfide (PPS).

3.2 Materials for *PolyJet* Production of Bridge Moulds

PolyJet and *PolyJet Matrix* processes enable the application of more than one hundred different materials based on acrylic resins, which can mimics the properties of the materials from elastic to rigid. For manufacturing bridge moulds, mould material have to be strong enough (tensile, flexural, compressive and bending strength), tough, and resistant to high temperatures to maintain mould cavity dimensions. Four materials can be separate as the most appropriate for the *PolyJet* bridge mould manufacturing: *RGD 525* (white high-temperature material) and *RGD 5160-DM*, *RGD 5161-DM* and *Digital ABS plus* (ABS-like green materials). Tab. 1 shows some basic mechanical and thermal properties of those materials.

Table 1 Properties of *PolyJet* materials suitable for mould production [10, 11]

Property/(unit)	RGD 525	RGD 5160-DM RGD 5161-DM	Digital ABS plus
Tensile strength/(MPa)	70-80	55-60	55-60
Tensile modulus/(MPa)	3200-3500	2600-3000	2600-3000
Flexural strength/(MPa)	110-130	65-75	65-75
Flexural modulus/(MPa)	3100-3500	1700-2200	1700-2200
Izod impact strength/(J/m)	14-16	65-80	90-115
Heat deflection temperature/(°C)	63-67	58-68	58-68
Heat deflection temperature (after hardening)/(°C)	75-80	92-95	92-95

Material RGD 525 is the strongest material, but its toughness is 5 to 7 times lower compared to the other materials. RGD-5160-DM is suitable for production of details with wall thickness down to 1,5 mm, while RGD-5161-DM for wall thickness down to 1,0 mm. If the highest impact resistant and shock absorption are requested, Digital ABS plus is the most appropriate. With hardening process in furnace (Fig. 7), heat deflection temperature can be increased for all materials up to 30 %.

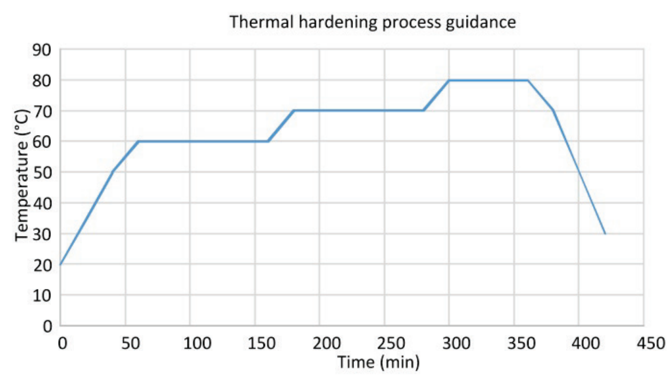

Figure 7 Process of mould insert hardening [12]

Increasing of heat deflection temperature is very important in application for mould inserts for injection moulding, where mould material is heated in cycles as hot polymer melt fills the mould cavity.

4 DESIGN RULES FOR BRIDGE *POLYJET* MOULDS

While design of bridge *PolyJet* moulds, it is possible to apply basic guidelines for design of classic moulds for injection moulding. However, because of specific *PolyJet* materials properties for production of bridge moulds, it is necessary to make some modifications in design concept.

This is necessary because of compensation of mechanical, thermal and dimensional characteristics of such plastic moulds. Some of the basic rules for design of *PolyJet* bridge moulds are [5]:

- increase the draft angles for easier moulded part ejection (Fig. 8),

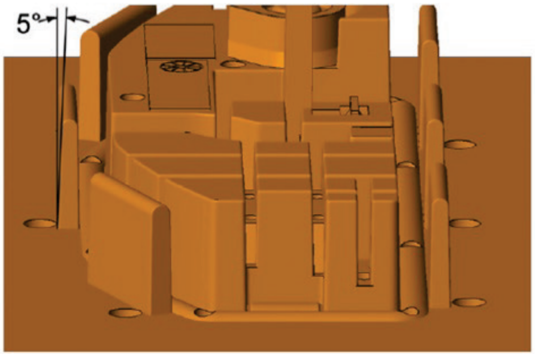

Figure 8 Increased draft angles [5]

- at all sharp edges add minimal radius,
- for building a 3D printed mould into a classic mould base, add at least 0,2 mm in height at the back face to improve mould closing and avoiding of flash (Fig. 9),

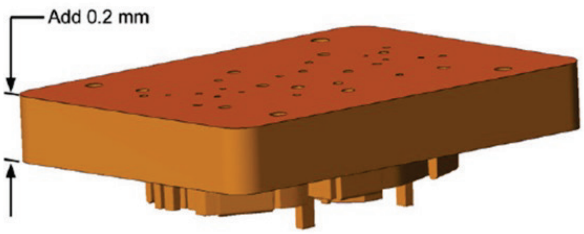

Figure 9 Extension of the back face of the core/cavity [5]

- while 3D printing of the core pin, it is recommended height/width aspect ratio of 3:1 (for larger aspect ratio it is recommended to use exchangeable metallic pins),
- while making holes, minimal diameter is 0,8 mm,
- for mould gate design, classic side, film, tab and ring gates are recommended (avoid tunnel and pin gates) (Fig. 10),

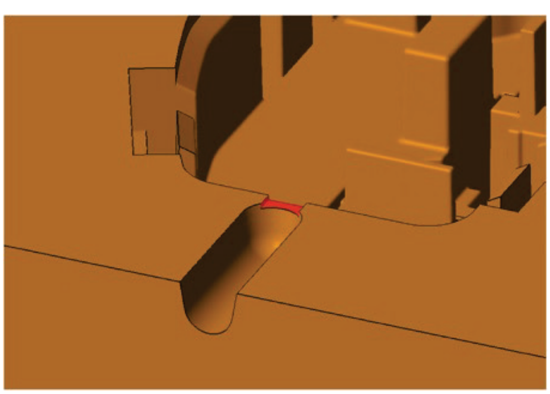

Figure 10 Typical bridge mould side gate [5]

- gate dimensions have to be 2-3 times larger than gate dimensions in classic steel moulds,
- gate thickness has to be equal or larger than maximal moulded part wall thickness,
- metallic sprue has to be built into plastic mould, in order to avoid direct contact of the plastic mould with hot injection moulding machine nozzle,
- build in classic ejector pins that are not placed on distances smaller than 3 mm from the mould cavity edge (otherwise, the mould can be damaged) (Fig. 11),

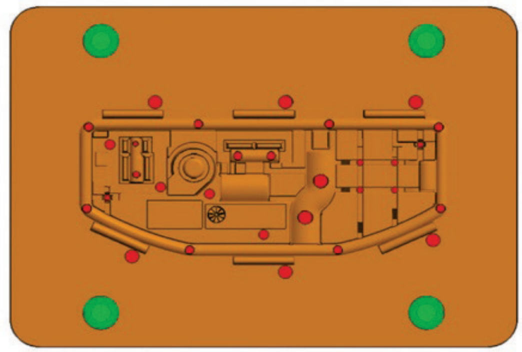

Figure 11 Moulded part ejection system [5]

- decrease the ejector holes diameters for 0,2 to 0,3 mm and adjust them for the ejector mounting into the mould insert with classical machining,
- complex mould cavity geometry has to be split into multiple mould inserts (Fig. 12), in order to achieve appropriate mould cavity venting through tolerances in inserts contact,

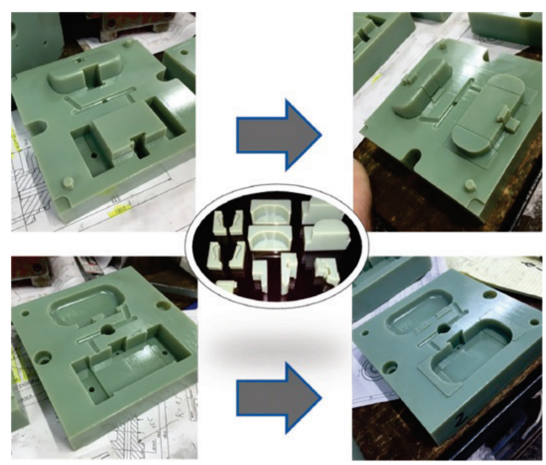

Figure 12 Multiply mould inserts [5]

- although, because of poor thermal conductivity of *PolyJet* materials, classic mould tempering by cooling channels and water as a coolant is not efficient, avoiding it can contribute to prolongation of the mould durability (expected up to 20 %) (Fig. 13),
- more effective cooling is done by blowing of compressed air on the mould parting plane,

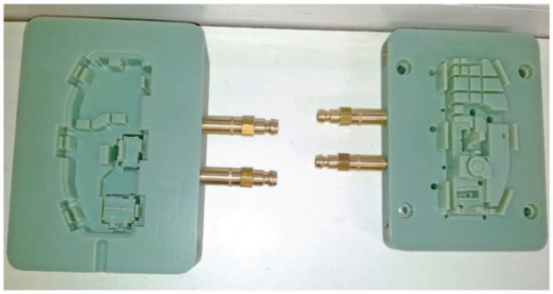

Figure 13 Cooling channels plugs [5]

- while preparing for 3D printing, mould insert should be oriented so that the mould cavity is up-oriented (glossy surface without support material), which will result with smoother mould cavity surface (Fig. 14),

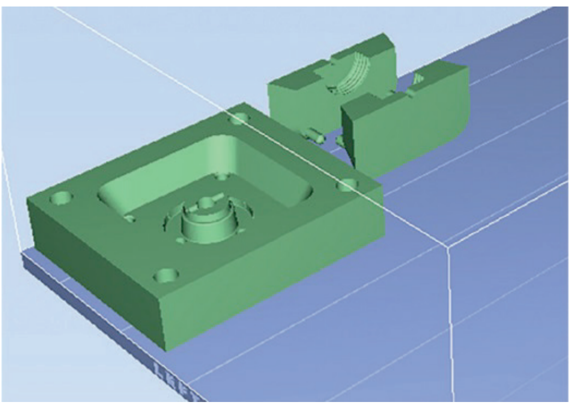

Figure 14 Orientation for glossy surface without support material [5]

- mould insert should be oriented on the building platform with larger dimension in line with the printing head moving direction (print lines) because in that orientation the material is better cured - it is longer exposed to the UV light (Fig. 15).

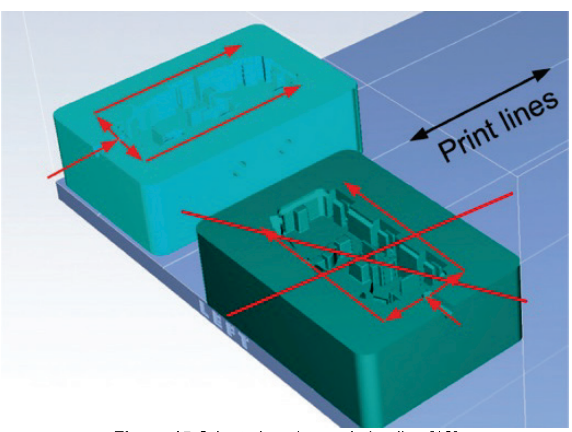

Figure 15 Orientation along printing line [12]

5 POSSIBILITIES OF *PolyJet* BRIDGE MOULDS APPLICATION

In the application of bridge *PolyJet* mould inserts, several approaches in embedding in standard mould bases or their independent application are possible. In the case of smaller injection moulded parts, it is possible to independently use *PolyJet* bridge moulds. Depending on the application of hand or mechanical injection moulding machines (Fig. 16), it is necessary to adjust *PolyJet* moulds dimensions correspondingly.

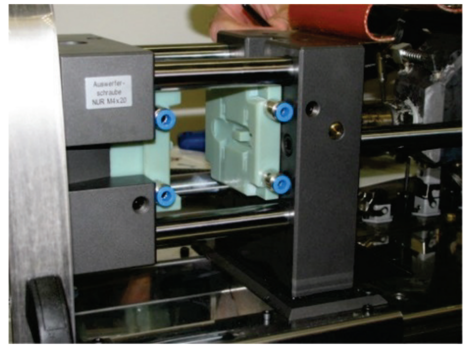

Figure 16 Bridge mould on injection moulding machine [4]

In the case of using a hand injection moulding machine, the designer has larger freedom in mould design and optimising its dimensions (Fig. 17).

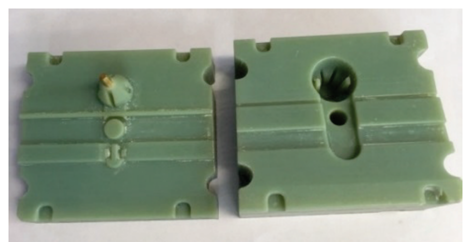

Figure 17 *PolyJet* mould for applications on hand-injection moulding machine [13]

When *PolyJet* moulds are applied on mechanical injection moulding machines, it is necessary to adjust mould dimensions to the injection moulding machine clamping plates and tie bars, as well as the rest of the mould base. Besides, it is necessary to enlarge the thickness of the mould plates, compared to the moulds aimed to operate with hand injection moulding machines, in order to avoid creation of cracks on the mould plates (Fig. 18).

Figure 18 *PolyJet* mould plate with cracks [14]

In the case of the production of large amount of moulded parts on larger injection moulding machines, *PolyJet* mould inserts have to be embedded into a steel mould base (Fig. 19).

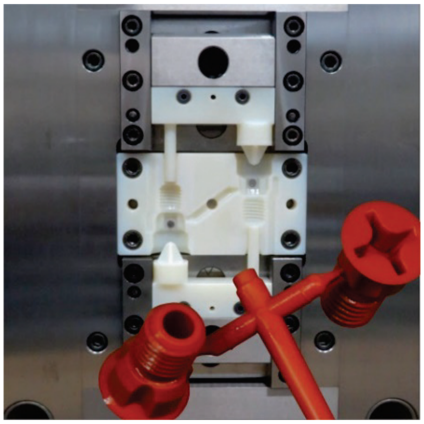

Figure 19 *PolyJet* mould inserts embedded into steel mould block [19]

6 CONCLUSION

The *PolyJet* process of 3D printing bridge moulds enables simple manufacturing of whole moulds or mould inserts in relatively short time. An additional advantage of this process is the 3D printing of moulds at room temperature, which will not cause mould shrinkage and deformation which otherwise have to be taken into account during mould design. Mould cavity walls are very smooth (because of application of material in liquid form), which enables easier moulded part ejection and smooth surface of moulded parts. In order to be successful in the application of *PolyJet* 3D printed moulds, general rules for design, manufacturing and post processing have to be taken into account.

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Notice

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Preliminary communication

Transformation towards Sustainable Business Models in Production: A Case Study of a 3D Printer Manufacturer

Shahban Ali Shah, Philipp Url*, Wolfgang Vorraber, Thomas Janics, Matthias Katschnig

Abstract: A global transformation from Industry 4.0 towards Industry 5.0 will soon take place. Such transformations are intrinsic to human and sustainable value creation. An increasing number of companies, recognising this imminent trend, will need to transform their current classical, solely profit-oriented business models into sustainable business models that also target human, social, and environmental aspects. Various frameworks already exist that support the design of sustainable business models. Practical applications of these frameworks and research on the transformation process in the production domain, which places a special focus on small and medium enterprises, is still scarce. This paper presents the first results from a sustainable business model transformation project on a European SME, which produces 3D printers. The research method applies a single case study design. The study was based on publicly available information and qualitative data, obtained through interviews and workshops carried out on an executive management level.

Keywords: 3D printing; business model; production; SME; sustainability

1 INTRODUCTION

A global transformation from Industry 4.0 towards Industry 5.0 will soon take place. Drivers for this transformation include the rapidly growing and changing digital technologies, the necessity to increase productivity, and the need for sustainable value creation. Pioneers and leaders in the industry are already trying to prepare for this transformation by working on solutions to increase sustainability. [1]

Sustainability includes the creation of social and environmental values, as well as economic values [2]. This transformation is also relevant to small and medium-sized enterprises (SMEs), which play an important role in industry throughout Europe, particularly in Austria, where 99.6% of all companies belong to this category [3]. Many companies have realised this trend and are adapting their strategies accordingly. To support these strategies, enabling companies to achieve more sustainability, this study was conducted to target the business model level, at which the fundamental logic of the company is determined [4, 5]. Companies will need to transform their current classical, solely profit-oriented business model into a sustainable business model, which also targets human, social, and environmental aspects [6].

This paper presents the findings of a study on companies that are still operating using a classic business model, placing a special focus on Austrian SMEs in the production domain. This study explores how a business can be transformed from a classical to a sustainable one. Various frameworks already exist that can be used to support the design of sustainable business models. These include the value mapping tool (VMT) [7], the triple layered business model canvas (TLBMC) [8], the strongly sustainable business model canvas [9], values-based innovation [10, 11], and the sustainable business canvas [12]. Practical applications of these frameworks and research on the development of a sustainable business model (SBM) in the production domain, with a special focus on SMEs, is still scarce [6].

This paper presents results of an explorative study on SBM creation by a European SME. This study was preceded by a preliminary study [13]. The research method applies a single case study design. The study was based on publicly available information and qualitative data obtained through interviews and workshops on an executive management level [14]. This paper includes additional steps needed to develop an SBM, including the procedure, applied tools, and practical insights gained from their application. Feedback in the form of survey responses from our company partner, intermediate results and the final SBM, visualised as a TLBMC [8] are also presented.

The company partner in our case study was HAGE3D [15], a 3D printer manufacturer, that is currently operating using a classical business model. HAGE3D is trying to present their product, with material extrusion technology [16], on the medical industry market. The medical industry represents a completely new market for HAGE3D, requiring them to create a new business model. At the same time, HAGE3D also wants to create a SBM.

This paper is structured as follows. The introduction is followed by a description of the conducted case study, including the applied research method, an overview on selected tools, and the workshop setup. The results section includes a description of the resulting SBM and how the data were generated. Finally, the conclusion, including limitations and an outlook of steps that should be taken in the future, is given.

2 CASE STUDY

Companies face several challenges as they adopt new sustainable business models (SBMs) [6]. To understand this problem more thoroughly, this case study was conducted in cooperation with HAGE3D, which is a family-owned Austrian 3D printer manufacturing SME, initially founded from HAGE Sondermaschinenbau [17]. Both companies are now connected under the HAGE Holding [18], which serves as its parent company. For several years, the company has conducted research on and produced various types of reliable

3D printers for their core customers, including original equipment manufacturers (OEMs), tier 1 suppliers, and SMEs of various industries, such as electronics, chemical, and automotive industries.

Recently, the top management of HAGE3D decided to target the medical industry. Therefore, the need for a new business model arose. The aim was not to introduce major changes into the existing business model, but instead to establish a complete new SBM for the medical industry from the initial business plan and onwards. The case study describes the application of specific tools and provides insights into the resulting SBM. [13]

2.1 Methods

The research method applied a single case holistic design. The study was carried out on the basis of publicly available information and qualitative data, obtained through interviews and workshops conducted on an executive management level [14]. A paradigmatic case of creating a specific SBM type was chosen which integrates the products and services of a 3D printer manufacturing SME [6].

2.2 Applied Tools

Fig. 1 provides an overview of the toolchain and the purpose of the use of each tool. The first two tools were included to emphasise the economic aspects of the business model. This provided a foundation that allowed us to explore the social and environmental aspects of the SBM. The stakeholder map [19] was used as starting point, identifying relevant stakeholders according to the categories defined by the tool. The business model canvas (BMC) [20] was used to identify the economic aspects of the business model. The BMC was very helpful, in that it enabled us to engage the workshop participants from HAGE3D, as they were already familiar with the BMC [20]. To identify social and environmental aspects of the business, the VMT [7] was applied. A VMT guideline published by [21] was used to support the workshop facilitators. Before creating the TLBMC [8], the values that were exchanged by the stakeholders were investigated using a value network analysis (VNA), modified from that presented in [22]. The value network revealed further social aspects of the business. The TLBMC [8] was used to summarize all gained data as SBM.

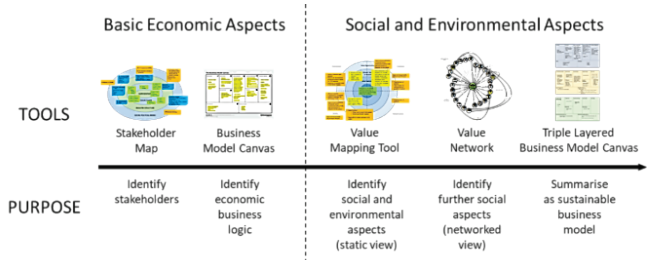

Figure 1 Overview of applied tools and related purpose in order of application. Stakeholder map modified from [19], business model canvas modified from [20], value mapping tool modified from [7], value network modified from [22], and triple layered business model canvas modified from [8]

All tools were introduced to the participants and printed in a large format before being applied in the workshop to foster the engagement of the company partners and allow them to generate the content collaboratively. The detailed workshop setup is described in the next section.

2.3 Workshop Setup

The results of this work are based on data gathered during a preliminary study [13], which included desk research, an interview, and an initial workshop, conducted together with executives from the partner company.

To proceed and gain further detailed information, a second workshop was conducted with the following stakeholders:

- CEO from HAGE3D.
- Head of R&D from HAGE3D.
- Researchers from the Institute of Engineering and Business Informatics, TU Graz.

The second workshop was facilitated by the use of a VNA [22], and feedback was collected through a survey regarding the tools used during the research period. The setup was designed to uncover opportunities for recognising additional sustainable value for the company and their stakeholders over the long run. All practical activity related to the workshop took place in a seminar room at the Graz University of Technology. First, the tools applied in the first workshop, stakeholder map [19], BMC [20], and VMT were revised. During the revision, additional data were collected on the basis of feedback from HAGE3D. To gain further insights, the theoretical background for the value network [22] was introduced to the participants of HAGE3D in terms of its functionality and its usage. In the beginning of the workshop, a simplified version of the VNA [22] was prepared using data from the stakeholder map and printed in a large format for use during the workshop. All identified stakeholders, including their attributes (i.e. names, capabilities, and assets) were connected with lines during the workshop as a result of input from HAGE3D. The aim of this step was to facilitate the creation of a simple, visual way to identify the exchanged values, avoiding the use of predefined generic categories. The executives of HAGE3D were asked to provide free-text answers to the question: What is exchanged between the actors on the chart? After the workshop, the value network was digitalised and, in combination with the results of the previous workshop, the TLBMC [8] was created. This is described in the following section.

3 RESULTS

In this section, an overview of how various tools are used in the process of developing a sustainable business model for a 3D printer manufacturer is provided.

The VMT [7], as shown in the Fig. 2, was used to compare conventional implants with 3D printed implants using material extrusion technology [16] [23]. The activity-generated outcomes for HAGE3D in the form of values missed, which further supported the process of depicting value opportunities, could be assigned to four dimensions (i.e. environment, society, customers, and network actors) in collaborative conversations about the different aspects.

The use of such a tool helped the researchers and the company executives during the process of identifying the promising social value opportunities, which had been missed when applying conventional manufacturing methods. In addition, an understanding developed that the material extrusion technology [16] has an overall stronger social impact as compared to its environmental impact [24].

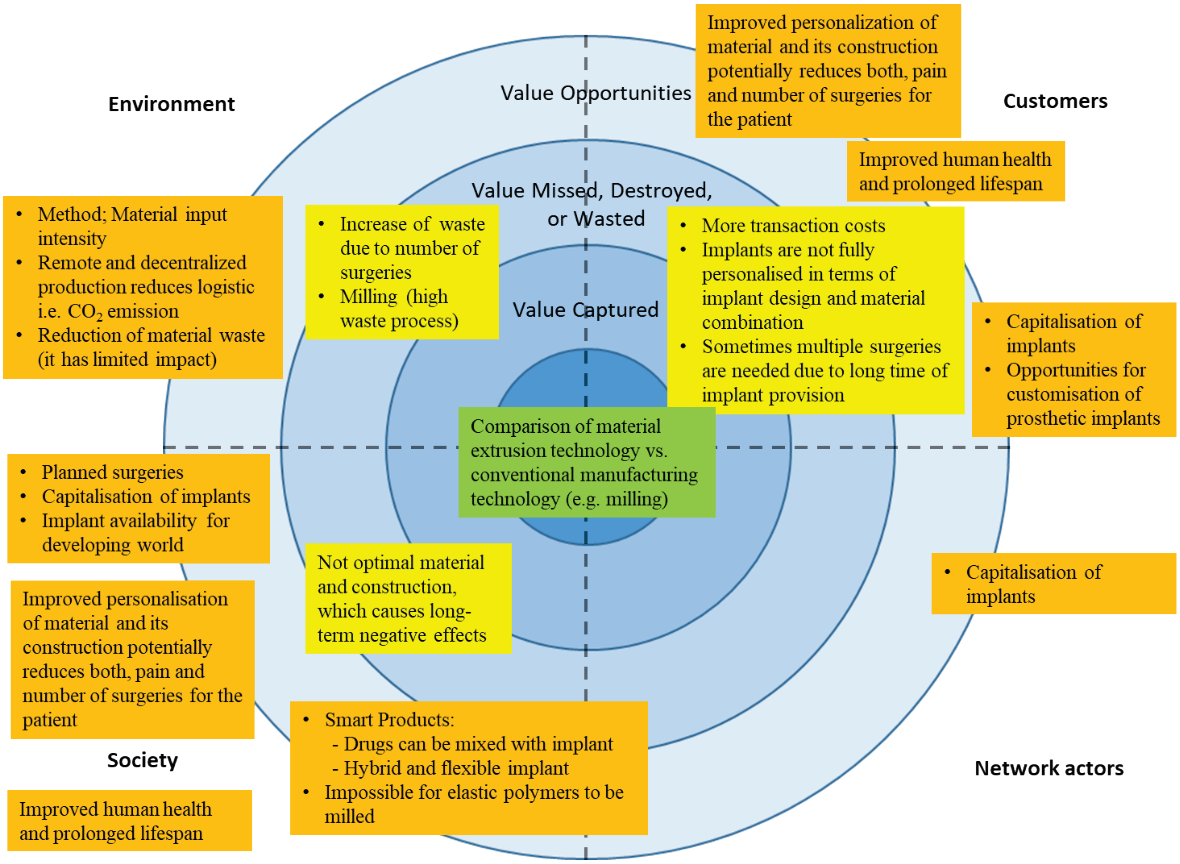

Figure 2 Value mapping tool based on [7] populated with data obtained from a workshop with HAGE3D

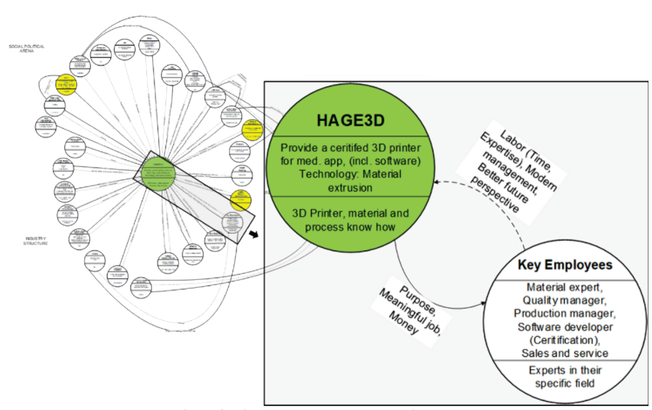

Figure 3 An analysis of HAGE3D's stakeholders performed with the value network. Simplified version, modified from that presented in [22]

In the next step, it was attempted to identify additional long-term stakeholder values by applying the VNA [22] during the second workshop with HAGE3D. Overall, Fig. 3 depicts the values exchanged between the multiple stakeholders present in the company's medical business ecosystem. The exchange of values, for example, between HAGE3D and key employees as two actors, is expanded to provide further illustration. The solid line conveys the information provided by HAGE3D to key employees regarding the purpose of, meaning of, and salary for the offered job. On the other hand, the dotted line represents the values provided by key employees to HAGE3D in terms of services, know-how, modern management, and better perspectives for the future. The resulting value network provides a good overview of the relevant stakeholders and the values they exchange in a networked medical business. The experience gained in this workshop also indicated that creating a stakeholder map [19] early on helped generate actors.

After adopting various tools, as shown in Fig. 1 and Fig. 2, the researchers were finally able to design a new SBM for HAGE3D using TLBMC [8]. The data obtained from the stakeholder map [19], BMC [20], VMT [7], and VNA [22] supported the creative exploration of economic, social, and environmental value for HAGE3D. These could be translated into economic, social, and environmental layers of the TLBMC as a final output [8].

3.1 Economic Layer of the TLBMC

The economic layer provides a systematic and detailed description of key aspects of how the company creates profit and delivers value to its customer via its supply chain in a network-centric manner [25]. The nine components, illustrated in Fig. 4, show the interpretation of the economic layer of the TLBMC [8] of HAGE3D in more detail.

Value proposition: The quest for the creation of economic value begins by providing a certified, flexible 3D printer for medical application. This includes the software needed for production management, which is certified for medical products as well, reselling of reliable material, and includes 3D printer settings (i.e. parameters are set for certain materials, but can also be adapted for other materials). Offering the customer process support engineering and providing the results of an initial feasibility study also contributes to the creation of value. The following 3D system packages are being offered in the medical sector:

- Printer + slicer software
- Printer + modelling + slicer software.

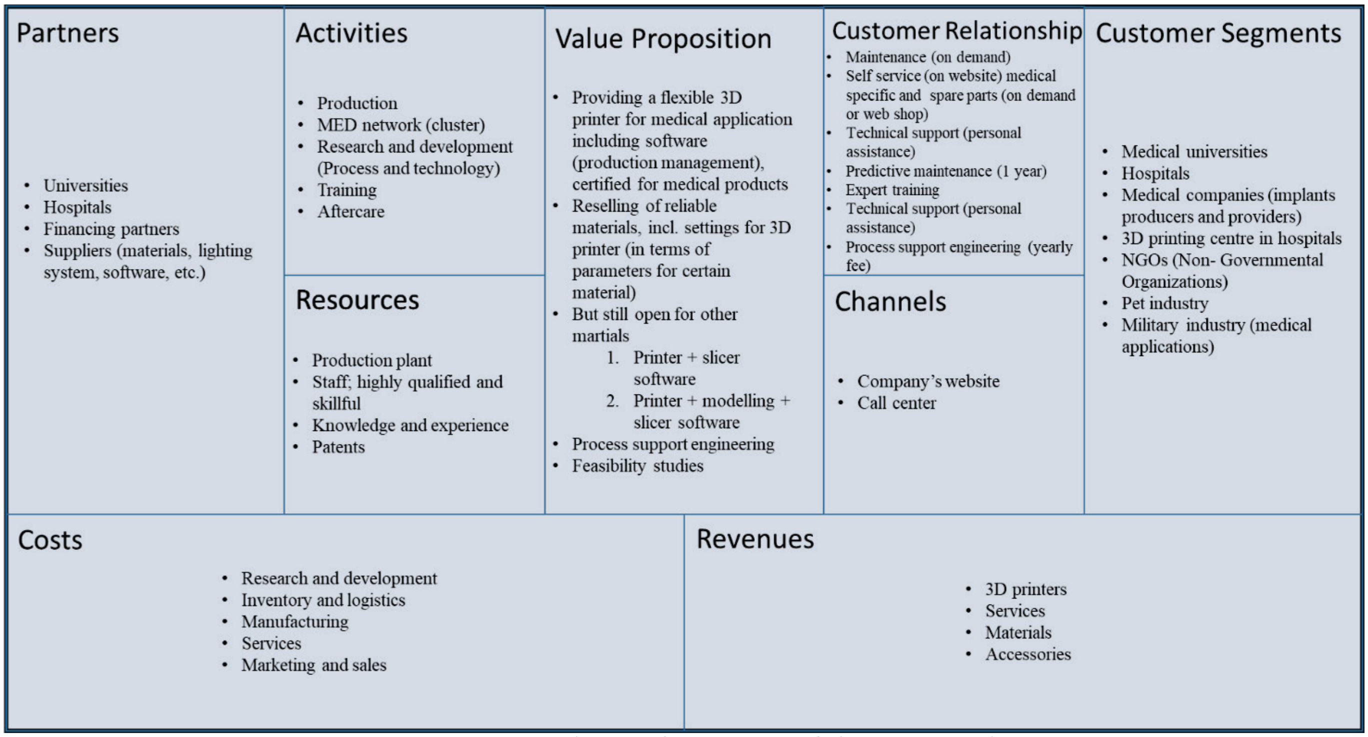

Figure 4 Economic layer of the TLBMC demonstrates HAGE3D case based on [8]

Key partners: The list of the company's key partners includes universities, hospitals, financial partners (e.g. banks), and various core suppliers of software, materials, and lighting systems.

Key activities: The medical cluster of various business stakeholders is vital to HAGE3D in that it offers possibilities to interact, follow new trends, and collaborate. The company's research team focuses on process and technological system development. Training on new developments is provided to staff and customers. After the 3D systems are sold, the company offers a customer care service.

Key resources: Both the company brand and patents are considered to be key resources. This list further includes intangible assets (i.e. the employees' knowledge, skills, and experience). Lastly, the production plant that manufactures the 3DP products is also a crucial company resource.

Customer segments: In general, all medical universities and hospitals are customers at the front layer, including medical implant producers and providers, whereas the 3D centres established in hospitals also use HAGE3D systems for research purposes. Non-governmental organisations (NGOs) and any military partners involved in humanitarian missions in remote parts of the world are also considered potential customers. The demand for customised 3DP products for pets might increase in the future. Therefore, the pet industry in general is also placed in this section.

Customer relationships: Offerings like personal assistance, technical support process engineering with a yearly fee, on demand maintenance, free predictive maintenance for up to one year, and the online or direct availability of medical specific products and spare parts will create a strong customer relationship. Meetings with members of the medical community in various forums and the provision of expert training for the usage of 3DP systems will further strengthen relationships with customers.

Channels: The direct communication channels for customers are the HAGE3D company website and a call centre. Scientific conferences and research projects are also channels which the company can use. Another possibility is face-to-face communication (e.g. for direct sales of their products and services).

Cost: Manufacturing, marketing and sales, research and development, inventory, logistics, and services (e.g. training, personal assistance, and maintenance) contribute to the total cost of the company.

Revenue streams: The company obtains its revenue from the sale of its printers and materials. Accessories contributes a small portion, but services offered by HAGE3D will be of great importance in the future in terms of revenue generation.

3.2 Social Layer of the TLBMC

The usage of the VMT [7] as shown in Fig. 2 proved to be very helpful in creating the social layer of the TLBMC [8]. The nine components of the social layer of the TLBMC [8], as shown in Fig. 5, provides a deep understanding of HAGE3D's role in terms how society generally interprets this.

Social value: The company's social value can be interpreted by considering the fact that it provides an additive manufacturing system that enables the production of smart medical products, which improve the quality of life for its end user. 'Smart' in this sense refers to the fact that the implants are personalised and fabricated with a material extrusion technology, making it possible for drugs to be added to the material during the production process.

Employees: The company has fewer than twenty interdisciplinary employees. The key employees comprise the business head, material expert, quality manager, software developer (certification), and salesperson.

Governance: HAGE3D is a privately-owned for-profit company which performs autonomous decision-making and values transparency towards their shareholders.

Communities: HAGE3D has one local networked community in the province of Styria comprised of various stakeholders, all of whom mutually develop and maintain beneficial business and social relationships. The company is located in two locations (rural and urban) where different business activities take place. The company produces 3D printers in Obdach (rural), while the team in Graz (urban) focuses on operations like business development, research and development, and building a strong network with other stakeholders.

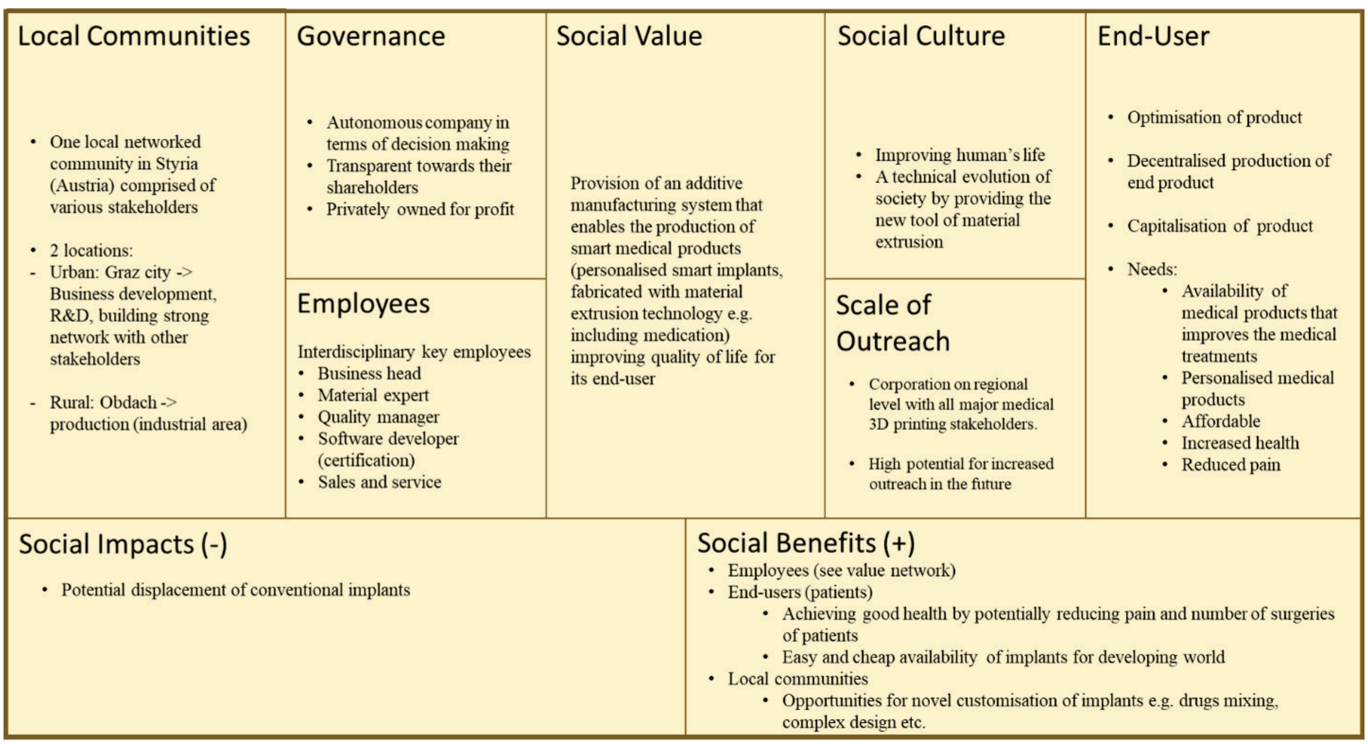

Figure 5 Social layer of the TLBMC demonstrates HAGE3D case based on [8]

Societal culture: HAGE3D has set the improvement of the quality of life of humans as its social agenda. A technical evolution of society by providing the new tool of material extrusion.

Scale of outreach: On a regional level, the company is in strong corporation with all major medical 3D printing stakeholders and possesses a high potential for increased outreach in the future.

End users: HAGE3D seeks to provide value by optimising, personalising, decentralising, and capitalising on medical products, i.e. fulfilling the needs of users by ensuring the availability of medical products which bring improve healthcare treatment by potentially reducing the number of surgeries and pain. In this context, 'capitalisation' means ensuring the affordable and secure availability of medical products in the future in developing countries.

Social impacts: Potential displacement of conventional implants may disrupt many businesses in the medical sector and could contribute to a rise in unemployment.

Social benefits: HAGE3D categorised social benefits as follows:

- Patients can achieve good health by experiencing a reduction in pain and a potential reduction in the number of surgeries by being quickly provided with access to better fitting, optimal end products.
- End users in developing world are provided with easy access to affordable implants for.
- Employees are provided with a sense of purpose, money, and meaningful jobs.
- Local communities can request novel customised forms of implants (e.g. in terms of drugs added to materials, complex designs) and benefit from the creation of new jobs.

3.3 Environmental Layer of the TLBMC

The most challenging part during the creation of the sustainable business model was to fill out the environmental layer of the TLBMC [8], based on the data extracted from using the VMT [7]. The use of the VMT [7] helped workshop participants discuss and identify the basic aspects of this dimension. But to obtain deeper insights into environmental aspects, participants realised that they would require the use of additional methods to completely fill out the environmental layer of the TLBMC [8]. Methods, such as the material input per unit of service (MIPS) [26] or life cycle assessment [27]. These methods support approaches that can be taken to measure the eco-efficiency of a product or service. Therefore, participants realised that it would be very difficult to claim a functional value only by using the tools presented. Nevertheless, environmental layer of the TLBMC [8] could be partially filled in and is presented in Fig. 6, based on data obtained from the use of the VMT [7] (see Fig. 2).

In this study, medical material extrusion technology was considered as the functional value. Although the impact of this technology is still quite low, the following benefits were taken into consideration. The consumption of input materials using material extrusion technology is less than that used by conventional subtractive technologies, and the use of material extrusion technology reduces the waste amount of input material to little or almost nothing during the production phase. The logistics of the process could also be simplified, due to the degree of flexibility and agility possible through the use of material extrusion technology; 3D printed medical products could be rapidly produced in a decentralised location, near the end customer.

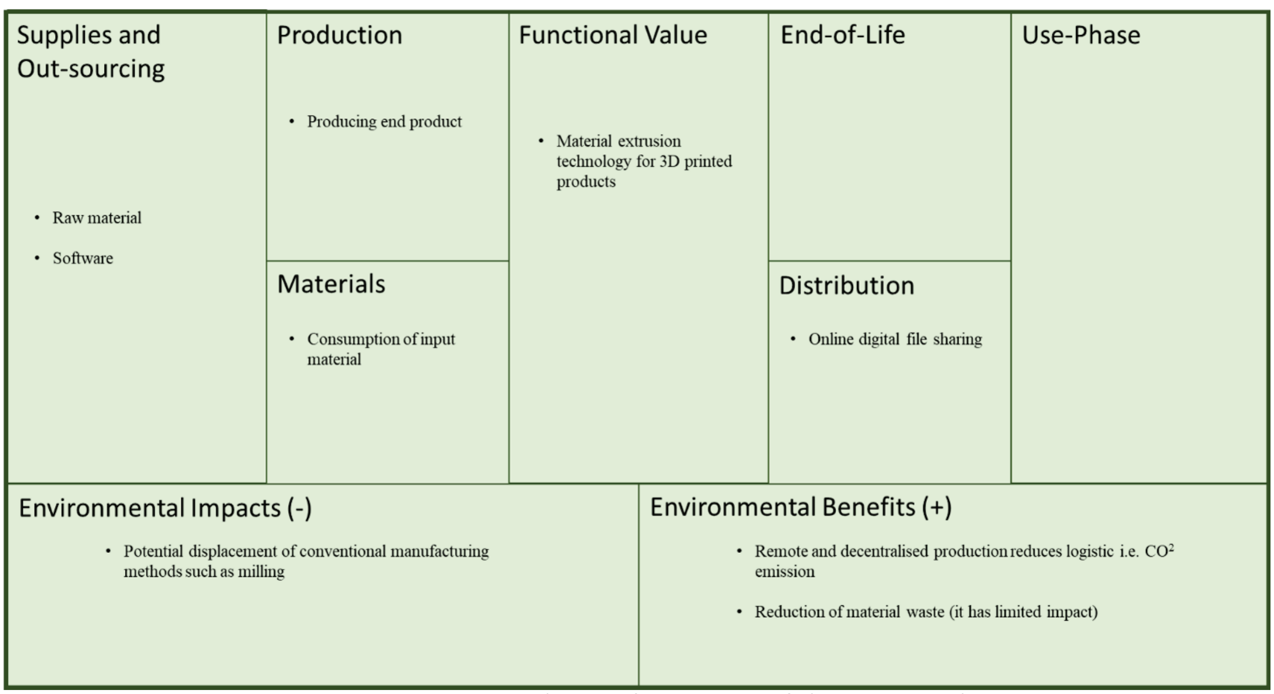

Figure 6 Environmental layer of the TLBMC demonstrates HAGE3D case based on [8]

3.3 Survey Feedback

At the end of the second workshop, a survey was conducted with the participants from HAGE3D to gain insights on the practicability of the tools applied in both workshops. The survey contained questions about all applied tools: their usefulness, ease of use, generated insights, choice of tools in the respective company and for what purpose, and choice of favourite tools and why.

Both participants from HAGE3D rated the value network tool as the most useful tool that had been applied in the workshops. The VMT [7] achieved an average rating in terms of its usefulness. Concerning the ease of use of a tool, the stakeholder map [19] was rated as the most difficult one. The value mapping tool and value network were rated as slightly easier to use than the stakeholder map. One participant rated the BMC [20] as the easiest to use, whereas the other rated it as the most difficult one. This result might be related to the previous experience participants had had with the tool. Both participants rated the VNA [22] as the best tool in terms of insights gained. One participant stated that he would use the stakeholder map [19] and the VNA [22] again in his company. The stakeholder map [19] was rated as useful for maintaining a general overview, and the value network was considered useful for developing cooperation, for sales-related activities, and for evaluating new business areas. The second participant stated that he would reuse the BMC [20] for business case development and the value network for market research and development.

4 CONCLUSIONS

This paper presents the results of a descriptive study on a process of transformation in an SME, namely, the process of developing a sustainable business model, including defining the procedure, choosing and applying specific tools. Our results indicate that the use of simple and well-known tools, such as a stakeholder map [19] and BMC [20], are beneficial as starting points to engage company partners. The use of the VMT [7] can help company managers during the process of identifying important social and environmental aspects. The creation of a value network [22] provides initial insights regarding the relations between the stakeholders and allows managers to analyse the value exchanges. The results of these steps allow users to explicitly and practically integrate economic, social, and environmental value in a holistic manner using the TLBMC [8] and provide them with an outlook for future steps.

4.1 Limitations

The tools and the procedure could be used by workshop participants to identify social layer aspects for the social layer of the TLBMC [8], but were not as helpful for gaining further insights regarding the environmental layer. A partial or full life cycle assessment [27] of printed medical goods would maybe give more input for this layer. The VNA [22] was applied while only considering the value exchange and resources layer, which places a stronger focus on the economic aspects of the TLBMC [8].

A holistic single case study cannot be generalised to other studies. Therefore, multiple case studies need to be carried out to test the applicability of these findings [28]. The case study is limited to one type of SBM (i.e. product-service system) and one type of sustainable business model innovation (i.e. sustainable business model diversification) [6].

4.2 Outlook

More detailed insights into the social and economic layers can be obtained by applying the VNA as described in [29], including values and needs layer, legal layer, dynamics and motivation layer. Multiple case studies still need to be conducted to explore this topic in depth [28]. Further case studies should also be conducted based on other types of sustainable business model innovation [6].

Acknowledgements

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Notice

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Preliminary communication

Industrial Service Engineering - Training Requirements for Systematic Service Development

Clemens Fischer*, Herbert-Michael Richter

Abstract: Increasing digitization and rising customer requirements represent an opportunity for companies in the machine- and plant engineering industry. For long-term success, combined packages of product and service must be offered, to gain additional revenues and a unique selling proposition. Basically, the advantages of these bundles are slowly establishing themselves in industrial companies. The problem is, that the development and improvement of these bundles run often unsystematically, without a strategy. In Austria, companies are facing the issue, that they are not able to develop new services, due to a shortage of specially skilled employees. This derives out of a lack of clear definition of educational requirements. In order to identify those gaps, an empirical investigation based on expert interviews was conducted and the current status of training requirements was defined. As a result, future service job profiles and potential trends for education and training in the service area of industrial companies were derived thus machine- and plant engineering companies can innovate their employee education strategy.

Keywords: digitalization; industrial services; new jobs; plant engineering industry; service engineering; training requirements

1 INDUSTRIAL SERVICES

In 2019, 70% of the gross value added in Germany was generated in the service sector [1]. This illustrates the importance of services for society. Services can have many advantages for both companies and private consumers. Customers can receive individualised, adapted services and companies are, in turn, able to gain competitive advantage. Additionally, services can be provided in various manifestations. [2] In addition to traditional private and business services (e.g. cutting hair, security service, tax advisors), there are more and more services that have only emerged and continue to emerge as digitalization progresses (remote service, online training, internet banking) [3]. The interaction between providers and customers will be successively accelerated by the technologies used. The issue of digitisation (Industry 4.0) is also driving the development of services in manufacturing companies. Digital technologies make it possible to connect systems in a company more closely with each other [4]. In addition, services can also be more individualized, adapted to customer requirements and offered in a more flexible and resource-saving manner [5].

In manufacturing companies today, services are implemented as meaningful enhancements of business models with the intention to increase the turnover and profit of a company. The increased offer of services in the product and service portfolio of companies is due to the fact that companies are forced by increased competitive pressure to differentiate themselves from the competition. [6]. Industry 4.0 solutions and the associated hybrid products, in which services are supported and upgraded with machines, are expected to generate significant sales growth, averaging 13% cumulatively over five years. The biggest challenges are, therefore, the high investments, the often still unclear economic efficiency calculation and the lack of standards and norms for industry 4.0 applications. However, expert companies also point to the insufficient qualification of employees [7].

2 NEW SERVICES NEED NEW THINKING AND KNOWLEDGE

The advancing digitalization changes the world in which we live and work in. Digitalization is revolutionizing entire industries, creating new business models and entering into all fields of professions [8]. The manufacturing industry is facing a fundamental change that affects both, its services and its production-/ work processes. New job profiles emerge that lead to changing demands on employees. Along with this, qualification requirements are also changing. Workers are expected to have all the skills necessary to adapt to technological change [9].

The development of digitization is also changing the old job profiles. Labour market experts assume that as the development progresses, above all, simple tasks will cease to exist. Konrad Wegener of ETH Zurich postulates that jobs for unskilled workers will cease to exist in Switzerland in the foreseeable future. In Germany, on the other hand, it is predicted that the loss of ancillary activities will be compensated by additional jobs created by digitisation [10].

According to a study by Ingenics and the Fraunhofer Institute for Industrial Engineering IAO, the requirements profile of production employees in particular will have to change. In the future, production will require people who, in addition to a high level of competence, also have the ability to act and think in an interdisciplinary manner. In addition, there are the skills required to understand complex processes and evaluate extensive data material [11]. The new requirements profile of people makes it necessary to adapt the contents of the training to the demands that arise from digitisation [12]. This means that forms of learning must be much more integrated into work processes and must be highly flexible and dynamically adaptable to changing requirements and different learning needs [13-15].

In this context, knowledge about new technologies has to be integrated into vocational and academic training [16]. Since the didactic possibilities seem almost unlimited, the question arises which teaching-learning methods and digital tools have to be selected to enrich existing and new learning opportunities. In this context, in addition to teaching content, the needs of the learners and the right choice of teachers are crucial [17].

In summary, it can be said that a stronger service orientation also places new demands on teaching staff [18].

The new requirement profiles for employees working in industrial services relate, for example, to IT skills and especially to data analysis, the results of which are increasingly providing the impetus for the development of new services [19, 20]. In addition to the focus on technical knowledge, modern services also require non-technical skills such as project management or skills in dealing with customers. However, non-technical skills are not only considered important in the context of services, but for the overall rollout of all technologies associated with digitalization.

The literature is currently not very specific on industrial services. This is due to the fact that the developments in this area are still very new in the industry and in some cases have rarely established themselves in companies. There are some literature sources that provide procedures for the development of new industrial services, but they hardly deal with specific requirement profiles for employees [21-23]. If the focus is on employee development, it is usually in connection with change management, organizational development or the necessity of lifelong learning or general mission statements [24, 25].

On the basis of this initial situation, the study programme Industrial Management of the FH-Joanneum carried out a study in cooperation with entrepreneurs in Austria. The aim was to obtain an empirical result of the trends and requirement profiles of employees in the professional environment of industrial services. The Styrian Service Cluster (subsequently called SCC) was selected as a partner for this study as a consortium of 25 Styrian companies. This professional association of companies promotes the transfer of knowledge on service-related topics, as well as the exchange of best practice experience and strives to implement joint projects for innovative service solutions. In the following chapter, the methodology and the results of the study are explained in more detail.

3 METHODOLOGY

The methodology of the empirical survey is based on the method and procedure according to Dubé/Paré [26], which distinguish between the phases of research design, data collection and data analysis, shown in Fig. 1.

Figure 1 Research approach (according to [26])

The procedure follows an iterative approach. Reflections and feedback loops are performed after each interview to further improve the interview process.

3.1 Research Design

The generation of requirement profiles for employees in the field of service engineering is a complex issue, so an active interpretation approach using qualitative research methods should be used [27]. Consequently, a comparative study based on expert interviews was carried out. Open-ended questions allowed the respondent to answer flexibly. This approach is likely to generate improved data quality [27]. In order to obtain a general statement, the comparative study uses a multi-case approach that includes several interviews on the same topic [28, 29]. Since the interviews also dealt with methods and approaches for identifying new training priorities for employees, this empirical study also represents an explorative approach [26].

3.2 Collection of Data

The data was collected through interviews with experts of the companies within the SCC. These were semi-structured interviews which, in contrast to standardised interviews, are open and adaptable to the respective situation. An interview guide was created in order to define a common theme, but also to create some degree of freedom regarding the questions and thier formulation.

3.2.1 Selection of Respondents

In order to be assumed to have the necessary experience and knowledge in relation to new services, the managers interviewed had to meet the following basic criteria:

- The respondent is an employee of a company that is a member of the SCC.
- The interviewee has responsibility in a service area.
- Service Engineering is already established in the organization of his company.
- The respondent's company already offers digitally supported services in addition to its main business.

From the 25 members of the SCC, 16 were identified by analysing the individual companies which were eligible for the survey based on their business models, customer structure and product characteristics. The response rate of this qualitative survey was 75% (12 of the 16 selected SCC-members). The companies that were interviewed are active in sectors such as industrial waste re-processing (2), energy provider (1), (special) mechanical engineering (5), logistics (1), technology and electronics (1), industrial services (2). The companies surveyed were founded between 1712 and 1996, but on average they have existed for about 85 years.

3.2.2 Interview Guide

The interview guide represents the fundamental structure for the interview with the experts. As a collection of all questions to be raised during the interview, the guide must ensure that the interviews have the same common focus. On the other hand, it should not be too restrictive so that the statements are as open as possible [24].

In terms of content, the interview guide is divided into six main sections, each dealing with one of the major research topics:

1. Questions on the integration of service offerings into the organization: Here, the importance of service in the company should be clarified.
2. Questions on the existing situation regarding service professions: the primary aim is to determine which activities and requirements are associated with service professions and which gap exists between the know-how currently available and the know-how deemed necessary from the point of view of the experts.
3. The third block of questions focuses on possible changes in business processes and on the future requirement profiles or further training requirements for service employees.
4. The fourth block of questions concerning personnel development in the company: Here the new and additional requirements and the future necessary number of employees and their training are enquired.
5. The fifth block of questions deals with whether the previously "non-existent" occupations are already advertised and whether companies in the vicinity have training facilities for these occupations.
6. Questions regarding necessary requirements: The prerequisites which must be fulfilled by employees working in industrial services in the future and which training contents must be the focus of training for industrial services were determined.

The Tab. 1 shows the questions that were used in the interview.

Table 1 Interview Questions

1. How is the service organization structured – centralized/decentralized?
2. How many employees work in the service department?
3. Current Service Professions
3.1 What activities and requirements go together with the mentioned professions (requirement profiles)?
3.2 Educational level of the employee (required minimum training)?
4. Future service occupations - Where is the journey going?
4.1 Which activities and requirements are associated with the above-mentioned occupations (requirement profiles/further training requirements)?
4.2 For which of the above-mentioned requirement profiles do you think it could be difficult to find suitable personnel?
4.3 Educational level of the employee (minimum training required)?
5. With regard to the additional/new requirements: Will you need more/less or differently trained personnel in the future?
5.1 What strategy do you pursue with regard to changed/new requirements in the respective professions? (further training of existing employees or acquisition of new employees)?
5.1.1 If you provide further training for existing employees, for which current service occupations in your company do you think further training/additional qualification is necessary? Which activities are changing / are dropped / are added?
5.1.2 In your opinion, what is the maximum duration of further training required for the respective occupation? (until the respective activities can be carried out as desired?)
5.3 What is the maximum cost of the further training required for the respective profession?
6. Are "new" service jobs already advertised?
6.1 Do you have problems finding interested / qualified applicants?
6.2. If so, what problems arise? If no: What do you think is the reason why you do not have problems finding interested / qualified applicants?
7. Do you already have institutions in mind which offer these further training courses?

A test run was carried out to validate the interview guide before its application. Subsequently, the interview phase was conducted from 30 March 2018 to 27 April 2018. Each interview was conducted in German and by telephone. Each of the interview partners received the interview guide in advance. On average, an interview with the twelve selected interview partners lasted about 45 minutes.

3.3 Data Analysis

The data collected from the expert interviews were analysed in terms of content. According to Gläser/Laudel [29] the following four steps were carried out: in preparation, the recorded interviews were converted into an ordered and uniform text. During the subsequent extraction, information was taken from the written text and interpreted. In the next processing step, the extracted information is sorted according to the main topics, the content is aggregated and redundancies are removed. After the information was processed, the data was evaluated to answer the research question.

On the basis of the future requirements and activities specified by the interview partners for the respective service occupation, further training requirements were derived, stored in the survey matrix and then validated and approved by the respective expert.

4 RESULTS

The interviewed experts from the various companies provided very specific information on the new requirements that employees should bring with them into their jobs and on what should of special consideration when selecting employees. In addition, the results presented the currently prevailing challenges of training and further education of existing employees at the educational institutions known to the experts. After their elaboration, the results were presented to the SCC. The companies used them to create new strategies for employee development and new requirement profiles. The results thus also incorporated into the ongoing development of the Bachelor and Master degree programme in Industrial Management at FH JOANNEUM. This survey has thus reached the top companies in the manufacturing industry, which are intensively involved in new services. From the point of view of the experts surveyed, with the background that their companies are all internationally active, the results of the study can also be transferred to similar companies in other countries if they want to provide comparable services.

4.1 Trends in Employee Requirements for Industrial Services

The survey identified six main trends with regard to the demands of employees. The new service-oriented professions in the industrial sector require not only technical skills, but also further skills. On the one hand, in the area of rhetoric, intercultural communication and service-related language use. On the other hand, due to the increasingly digitalised technology of the systems and the services that have become possible as a result, an expanded level of knowledge is essential in the area of IT in addition to hardware know-how. Digital services can be used to support customers or plants all over the world. In order to follow the profitability calculations of the companies, these increasingly local subcontractors at the customer's premises are being used, which are trained by the manufacturer's trained technicians. To this end, tech companies offer communication solutions such as data glasses with video conferencing functions. As a result, the specialized service staff has to take over the leadership of the teams on site. This requires leadership and management skills and languages, at least English.

The exact trends and their corresponding aspects can be seen in Tab. 2. They were summarised from the experts' answers and prepared in text form below.

Table 2 Visualisation of trends

Technical
Solid technical basic training is required
Social Skills
Rethoric
Intercultural communication
Service wording
Business knowledge
Basics and wording of business administration/accounting/controlling
Information Technology
Understanding of syntax
Data analytics
Data scientist
Language
Fluent business English
Second foreign language
Leadership/General Management
Project management
Quality management
Negotiation training

4.1.1 Technical

One of the most important statements regarding current or future service occupations was, that people with a solid technical education, such as a degree from a higher technical college or an industrial engineering degree, are preferred. In the service sector, companies consider technology to be the most important area, which is why the technical foundation should already be in place before a potential new employee joins the company or after completing an apprenticeship. The companies demand know-how in areas such as mechanics, mechanical engineering, electronics and electrical engineering. It is not uncommon for basic knowledge of information technology to be required.

4.1.2 Social Skills

All of the responsible persons interviewed stated, either at their own initiative or upon request, that social interaction is very important, especially for employees that are in contact with customers. In general, several focal points can be derived from this. Companies want employees who are well versed in rhetoric and can argument aspects well and objectively. Furthermore, knowledge on topics such as claim management, conflict management and intercultural communication was also mentioned. How do I behave in conflict situations? How do I avoid conflicts at all? What does it mean to possess social competence? All the aspects that employees should be given in the course of training. It should not remain unmentioned that some companies also attach great importance to presentation techniques. This should therefore also be taught in the course of training.

4.1.3 Knowledge of Business Administration

Business management knowledge is essential, especially for technicians who have a management position in the company. Above all, knowledge of accounting (reading or interpreting a balance sheet and profit and loss account) and controlling (cost accounting) is required. Nearly all of the interviewed entrepreneurs were also convinced that it is much easier to explain the basics of business administration to a technician than it is to impart technical knowledge to a business economist.

4.1.4 Information Technologies

Nearly all of the companies surveyed are of the opinion that IT skills will be increasingly required of employees in almost all service professions in the future. In addition, due to the process character of the technical procedures in which the service technicians work, an ever deeper understanding of the interrelationships of the digitalized industry is required.

4.1.5 Languages

Another important aspect from the point of view of the service managers surveyed, is the level of proficiency in foreign languages. In Austria English is considered a basic requirement (spoken and written) in most companies. A significant number of companies are also of the opinion that mastering a second living foreign language will be relevant in the future. This means an additional to German and English language, for example, French, Spanish or Russian. This is particularly important in view of the increasing globalisation in various industries. The choice of language depends on the company and its partners or customers and varies from industry to industry.

4.1.6 Leadership

It is not without reason that the topic of leadership was excluded from the social skills trend. The background is that several companies stated that not every employee will automatically hold a leadership position in the future. However, with regard to the training of managers, the companies surveyed would like to see

- a general improvement in leadership behaviour,
- training in the field of conflict management,
- training/knowledge in the field of intercultural communication,

- negotiation training
- training to improve self-presentation
- and knowledge of project management.

4.2 Problems Mentioned by the Interview Partners

The experts specified the various requirements that will be demanded from employees in the future due to the changed product range for industrial plants. In addition, they also expressed their views on the challenges that are also connected to the training and further education and the image of services. On the one hand, this concerns the duration of additional training and the corresponding regulations of the training institutions, such as compulsory attendance. On the other hand, the association of the word "service" is often still strongly anchored in the gastronomic sector or is associated with dirty work in the industrial sector.

4.2.1 Duration of Training or Access Regulations

Almost all companies complained about a central problem, namely that most of the training courses they were aiming to offer, were not accessible to a large group of people. This is, on the one hand, due to the fact that companies on average do not want to exceed a training period of one to a maximum of two years, and on the other hand to the fact that employees who do not have an intermediate school leaving certificate (apprenticeship training/master school) are refused interesting training opportunities. In concrete terms, this means that an excellent technician with enormous know-how cannot get the necessary teaching content, as this is handled in a master's degree course. This is where companies would like to rethink the access regulations of the universities.

4.2.2 Compulsory Attendance at Teaching Institutes

The compulsory attendance obligations imposed on employees who complete their training on a part-time basis represent a major challenge for companies. Particularly with regard to service technicians who work in the field, attendance obligations represent a major hurdle. On the one hand, service technicians often cannot be sent on longer trips and, on the other hand, they cannot travel over the weekend because of training courses on Saturdays. For this reason, at least in the opinion of many of the companies surveyed, there should be a larger number of e-learning units. This would be a logical consequence of increasing globalisation and rapidly advancing digitalisation. Employees would be able to better plan their work and at the same time, they could attend lectures, trainings or courses from almost anywhere in the world.

4.2.3 Image of "Service" and Recruiting of Suitable Candidates

One topic that was mentioned by almost all the companies surveyed is the poor service image. The companies are of the opinion that the service sector is negatively affected, mainly because of most people associate service either only with the catering industry or alternatively with a hammer, wrench and dirt (as formerly mentioned in 4.2). This, in turn, means that job advertisements hardly succeed in attracting qualified and well-trained potential employees. No matter how well the job itself is described or circumscribed, applicants do not even look for vacancies in the service sector on various application portals. If many of the interviewees are of the opinion that this is the case, then academically trained people, in particular, are not aware of the exciting and at the same time challenging professions and activities the service sector has to offer. It is not without reason that the SCC already tried several years ago to find out what people living in Austria associate with service by means of interviews with passers-by in a pedestrian zone. The interviewed companies were or are in agreement that the image of the service sector needs to be improved.

A major result of this survey was also that many companies mentioned a relatively young profession, the data scientist. This is an expert in the field of data analysis and has the task of utilizing the constantly growing amount of data (in operation, for example through condition monitoring systems or predictive maintenance) in the company. With predictive maintenance, a correct interpretation of large amounts of data can give a significant competitive advantage over competitors who continue to maintain reactive service.

5 CONCLUSIONS

The creation and implementation of industrial services pose completely new challenges for companies in the manufacturing industry and their employees. Many people do not yet know where the journey of the new industrial (r)evolution and the possible accompanying change of business models will ultimately lead to, but companies can begin to prepare their employees for this change. Important points here are a better information policy and consistent training and further education in all areas.

One of the most important aspects of the training and further education of employees in the industrial services sector is the recognition of trends in the skills required by the services and expected by the customers. To summarize the trends that have been identified, it should be noted that companies need well-trained all-rounders, who combine knowledge and skills that have previously been divided among many people.

To this end, however, the development of transparent processes within the company must also be promoted so that closer cooperation between different departments does not fail due to a lack of understanding. In addition, the motivation of employees must be strengthened and the fear of change reduced. This includes involving employees from all departments more closely in internal information processes.
In-house and external further training promoted by the company is also proving its worth in order to positively prepare employees for the new challenges. In order to make the image of the service profession more attractive, a joint marketing campaign by the companies must be promoted.

This also includes the possibility of completing the necessary training courses virtually, which has so far only been done selectively. The current Covid19 situation, in which teaching is exclusively virtual, can provide an impetus for educational institutions such as colleges and universities to expand their e-learning offerings for the benefit of companies and in view of the need for well-trained employees.

Basically, not only the companies in the industry are at the beginning of a change in the new skills required from employees and managers, but also the applied research in many fields is facing a new challenge. New technologies make new hybrid products possible, but also require new methods to impart the necessary knowledge. This is where training institutions are called upon to find a practicable solution in close cooperation with the industry.

The study determines necessary service-related skills, beyond the technical/technological capabilities of the employees. Further studies of the Institute of Industrial Management will address the necessary service-related skills related to the new digital technologies which were not the subject of this study. Equaly, obstacles to the training of working professionals with secondary education (without a bachelor's degree) will also need to be surveyed, as companies and their employees do not only have access to M.Sc. level training.

Notice

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Study on the Deformation behaviour of Non–Hardenable Ferritic Stainless Steel (grade X6Cr17) by Hot Torsion Tests

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Abstract: The knowledge about the characteristics of deformability (deformation resistance and plasticity) has for the technologist, as well as for the designer and researcher, a great practical significance, because they are important elements in establishing a correct technological process. The change of deformation conditions existing in the industrial process, such as the temperature and rate of deformation, are difficult to consider for correcting the deformability determined by testing. The chemical composition of the material influences the plasticity and its deformation resistance both by the nature and distribution of the alloying elements and by the phase transformations they produce. In this paper, through "deformability", we cover all properties characterizing the deformation behaviour of alloys. In this sense, "deformation resistance" is expressed through the unit strain required to produce a certain degree of plastic deformation, under the conditions of a particular diagram of tensions, deformations and deformation rates, in the absence of external friction forces. Plasticity, being the ability of metallic materials to deform plastic under the action of external forces, is influenced by a number of material characteristics (chemical composition, structure) and other factors characteristic of the deformation (temperature, degree and speed of deformation, applied mechanical scheme). Plasticity is characterized, in the torsion test, by the number of rotations made by the specimen until breakage. A number of methods have already been used for the study of deformability. This study includes the results of hot torsion tests conducted to find the plasticity and deformability characteristics of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), which is a flexible grade of the stainless steel family with properties closely matching those of the more popular and expensive austenitic grade.

Keywords: deformability (plasticity and deformation resistance); ferritic stainless steel; hot torsion tests; grade X6Cr17; stainless steel grades

1 ABOUT FERRITIC STAINLESS STEELS

The fundamental criterion in the selection of stainless steel is generally that it can survive with virtually no corrosion in the environment in which it is to be used [1, 2]. The choice among the stainless steels that can be used in that environment is then based on the alloy from which the component can be produced at the lowest cost, including maintenance, over the intended service life [1, 2].

The main factor in the selection process for stainless steels is corrosion resistance [1–8]. Careful consideration of the application should be done to enable the choice of a grade with suitable corrosion resistance whilst keeping the costs on an economic minimum [1–5, 10]. Other considerations such as mechanical properties (strength and toughness), physical properties (magnetic permeability) and forming, fabrication and the joining methods available should be secondary in any material selection process [1–3]. Good engineering practice sometimes requires that materials be selected for sufficient, but finite, service life [3–9]. This is especially true for high–temperature service, for which creep and oxidation lead to a limited life for all materials [3, 9, 10].

Because of the stainless steel's corrosion–resistant properties, the material is often used in the fabrication of components used in the food and pharmaceutical manufacturing [1, 2]. Typical applications for ferritic stainless steels include petrochemical, automotive exhaust systems, heat exchangers, components for furnaces and food equipment, to name a few. With a greater strength than that of carbon steels, ferritic stainless steels provide an advantage in many applications where reduced weight are necessary, such as automotive emission control systems [4–8]. As with any engineered material, it is up to the user to specify what is needed for the application not over–engineered, which will cost more, or under–engineered, which exposes some degree of risk during usage [3–5]. Knowing the limitations and constraints associated with the many choices is a good step in determining the optimum material for each application.

Ferritic stainless steels are less expensive for the same corrosion resistance [1–3, 11]. Ferritic stainless steels are classified in the 400 series, usually with 10–30% Chromium content, and are often chosen for their excellent corrosion resistance and elevated temperature oxidation resistance. Standard ferritic stainless steels contain 10–27% Chromium, usually 16–20%, and are Nickel–free. Because ferritic stainless grades do not have Nickel, they are generally of lower cost than the 300 series grades [2–4]. Because of their low Carbon content (less than 0.2%), they are not hardenable by heat treatment and have less critical anticorrosion applications, such as architectural and auto trim [1, 7, 9]. Even though austenitic grades typically have better general corrosion resistance, formability, and weldability, some applications use ferritic stainless steels too [9–12, 16]. In elevated–temperature applications, ferritic grades provide better tensile–property stability and thermal fatigue resistance. They have lower thermal expansion and higher thermal conductivity than austenitic grades [2, 9–13, 16]. The standard ferritic stainless steel's chemical composition of corrosion–resistant high–temperature steel, grade X6Cr17, is presented in Tab. 1 [11, 14, 15].

Table 1 Chemical composition of corrosion–resistant high–temperature steel for grade X6Cr17 [14, 15]

C (%)	Mn (%)	Si (%)	S (%)	P (%)	Cr (%)
max. 0.12	max 0.8	max 0.8	max 0.025	max 0.035	16 – 18

Plasticity, being the ability of metallic materials to deform plastic under the action of external forces, is influenced by a number of material characteristics (chemical composition, structure) and other factors characteristic of deformation (temperature, degree and speed of deformation, applied mechanical scheme) [3, 9–13, 16].

The chemical composition of the material (ferritic stainless steel / non–hardenable stainless steel) influences the plasticity and its deformation resistance both by the nature and distribution of the alloying elements and by the phase transformations they produce [10–12].

2 RESEARCH AREA

As we mentioned above, the processing of alloys via plastic deformation is based on the property of plasticity, which defines their ability to acquire permanent deformations under the action of external forces [9–13]. When processing by plastic deformation, the shape modification of a semi–finished product is made by redistributing its elementary volumes under the action of external forces; therefore, unless some unavoidable losses occur due to equipment imperfection, processing takes place without any removal of material [3, 11].

The deformability of alloys characterises their ability to permanently deform without breaking the internal links. As the deformability of a material is expressed by the degree of deformation to which the first cracks appear, i.e. its tearing resulting from a standard mechanical test or from one specific to the industrial deformation process, it should be pointed out that the breaking process, for all industrial processes of plastic deformation, as well as for the materials plastically deformed in these processes, appears in the form of ductile fracture [2–5].

The knowledge about the characteristics of deformability has for the technologist, as well as for the designer and researcher, a great practical significance, because they are important elements in establishing a correct technological process [3, 9–12]. The change of deformation conditions existing in the industrial process, such as the temperature and rate of deformation, are difficult to consider for correcting the deformability determined by testing [9–12, 16]. In view of this, deformability is the ability of a material to be plastically deformed without the occurrence of undesired conditions (cracking of material during the plastic deformation, inadequate quality of surface, wrinkling or curling of stamped steel sheets, coarse structure, difficulty of material flowing when filling the moulds, or other commercially–imposed conditions) [9–12, 16].

Bearing in mind that different plastic deformation processes have specific mechanical deformation schemes and as different factors have a different influence on the plasticity and deformation resistance of metallic materials subject to deformation, until at the moment it has not been able to find a universally valid method of determining absolute values directly applicable for the calculation of plasticity and resistance to deformation [3, 9–12, 16]. Because of this, different indirect simulation methods are today used for the study of deformability. The values thus obtained can only be used to compare the behaviour relative to the deformation of the analyzed metal materials [3, 9–12, 16].

To date, a number of methods have already been experienced for the study of deformability, including the torsion, compression, bending or rolling of specimens of various shapes and sizes [9–12, 16]. There are several methods for determining deformability, such as:

- by compression, rolling or forging (taking into account friction) [9–12,16];
- by tensile, bending or torsion (without taking into account friction) [9–12,16].

The above-mentioned methods make it possible to study – besides the determination of deformability characteristics (plasticity and deformation resistance, depending on temperature) – the influence of deformation conditions (rate of heating, holding time at heating temperature, friction with the tools, rate of deformation, structural changes in terms of deformation, rate of recrystallization, etc.) [9–12, 16].

3 METHODOLOGY

Currently, the hot torsion test, which is an effective means of studying the plastic deformation skills of metals and alloys, seems to be considered, as a result of experience, as one of the best deformability tests. The main advantage of a torsion attempt lies in the possibility of obtaining important deformations made at constant speeds at a given point of the specimen, without disturbances in the flow of a deformed metallic material [9–12,16]. Moreover, the rate of deformation, the degree of deformation and deformation temperature can be imposed.

Thus, the torsion test allows the simulation of a thermomechanical cycle to be completed to a continuous blade and for the mechanical aspect and the metallurgical aspect of one or more deformations to be analyzed. The hot torsion test allows for the plasticity of the analyzed alloy and resisting deformation to be directly studied.

The determination of stainless steel deformability by torsion is the only one that makes it possible to obtain large deformations along the length of the specimen, which is why it is mainly used to determine the characteristics at large deformations [3, 9–12, 16].

Since shear strains play an important role in the process of rolling and forging, the deformability caused by torsion reflects quite accurately the steel behaviour at hot plastic deformation, and due to the fact that the specimen can be maintained in the oven during deformation, we can ensure the stability of temperature [3, 11, 12, 16]. Via this method, the hot deformability of stainless steel is determined by subjecting to torsion a cylindrical specimen maintained at the deformation temperature in a tubular oven [11, 12, 16]. The size of the required moment for the torsion of the specimen expresses the resistance to deformation, and the number of torsions before failure expresses the plasticity limit of that steel [11, 12, 16].

The laboratory equipment used to study the deformation behaviour of non–hardenable ferritic stainless steel by hot torsion belongs to the Faculty of Engineering Hunedoara, University Politehnica Timişoara [9–12, 16]. The specimens for hot torsions were mechanically taken from ∅20 mm hot–

rolled steel bars, having the form and dimensions presented in Fig. 2 [9–12, 16].

The test specimens are typically cylindrical, with a calibrated small–diameter central portion, having the ration l/d=5 in the point of deformation (Fig. 1) [11, 12, 16]. The ends are screwed, and the specimen must have a shoulder in the continuation of the thread, to prevent further screwing during torsion (Fig. 1) [11, 12, 16].

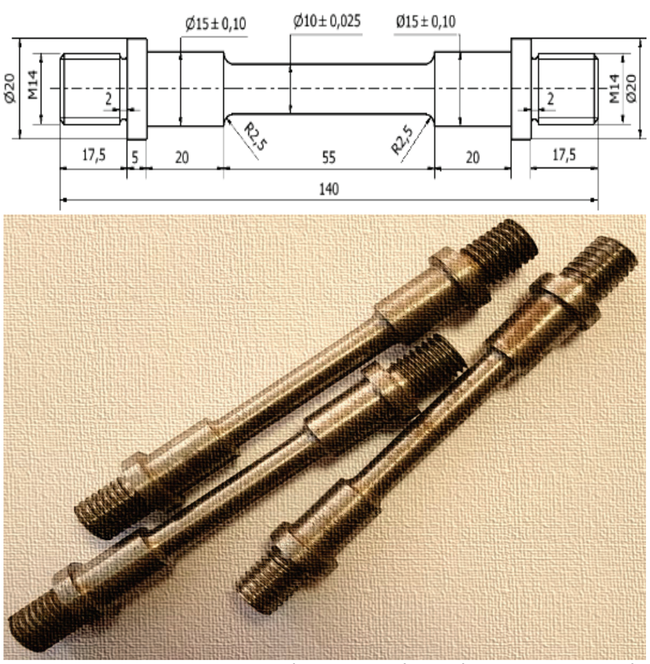

Figure 1 The test specimens used for the study of the deformation behaviour of non–hardenable ferritic stainless steel by hot torsion

4 RESULTS AND DISCUSSION

For experimental tests, we used several stainless steel grades. This study includes the results of the tests conducted to find the deformability characteristics (plasticity and deformation resistance) of ferritic stainless steel, grade X6Cr17 (Tab. 2) [11, 15].

Ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17) is resistant to corrosion in most environments. The grade of X6Cr17 is characterized by its good corrosion resistance and is displayed in immoderately corrosive environments. Stainless heat–resistant steels are always in demand when extreme technical requirements are imposed on the material, due to their outstanding chemical corrosion and mechanical properties [1, 3, 11].

For the hot torsion test, we prepared 40 samples from each steel grade (according to the experiments presented in Tab. 2). They were subjected to torsional deformation by maintaining the deformation temperature in the experimental equipment, from 50 to 50 °C, within the range of 800–1250 °C [11, 12, 16]. Each point within the temperature range studied in the two diagrams (Fig. 2 and Fig. 3) represents the arithmetic mean of four determinations.

The magnitude of the torque required for the specimen's torsion expresses the resistance to deformation, and the number of torsions to failure expresses the plasticity limit of that steel (Fig. 2). The plasticity limit is expressed by the number of torsions to failure at a given temperature and deformation rate (Fig. 3) [3, 9–12, 16].

Deformation resistance is the resistance posed by metal plastic deformation materials under the concrete conditions of the plastic processing process (friction conditions, temperature, degree and deformation speed, and mechanical deformity scheme) [11, 12].

Table 2 The results of the tests conducted to find the deformability characteristics of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C)

Experiments no.	Series no.	Heat–testing temperature, (°C)	Torque moment, (daN·cm)	Number of torsions up to breaking, (–)
Ferritic stainless steel – I	01.	800	135	31
	02.	800	133	34
	03.	800	140	42
	04.	800	138	40
Ferritic stainless steel – II	05.	850	126	29
	06.	850	126	22
	07.	850	123	26
	08.	850	122	24
Ferritic stainless steel – III	09.	900	108	27
	10.	900	112	17
	11.	900	111	29
	12.	900	112	29
Ferritic stainless steel – IV	13.	950	94	34
	14.	950	73	33
	15.	950	77	28
	16.	950	75	27
Ferritic stainless steel – V	17.	1000	63	35
	18.	1000	57	36
	19.	1000	57	48
	20.	1000	58	48
Ferritic stainless steel – VI	21.	1050	26	62
	22.	1050	22	58
	23.	1050	38	68
	24.	1050	28	62
Ferritic stainless steel – VII	25.	1100	83	15
	26.	1100	36	71
	27.	1100	41	75
	28.	1100	41	72
Ferritic stainless steel – VIII	29.	1150	29	78
	30.	1150	28	69
	31.	1150	29	94
	32.	1150	28	94
Ferritic stainless steel – IX	33.	1200	21	43
	34.	1200	21	57
	35.	1200	20	64
	36.	1200	20	67
Ferritic stainless steel – X	37.	1250	18	82
	38.	1250	16	89
	39.	1250	14	97
	40.	1250	14	93

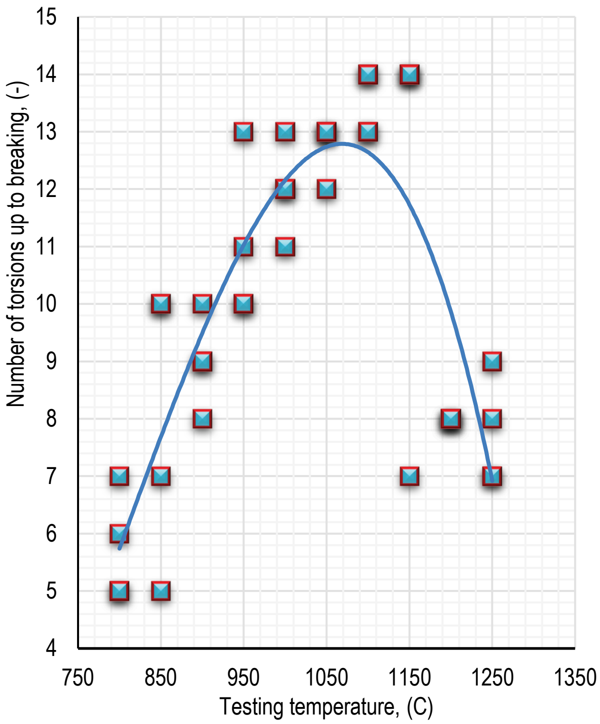

Figure 2 Correlations: Testing temperature vs. Number of torsions up to the breaking of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C)

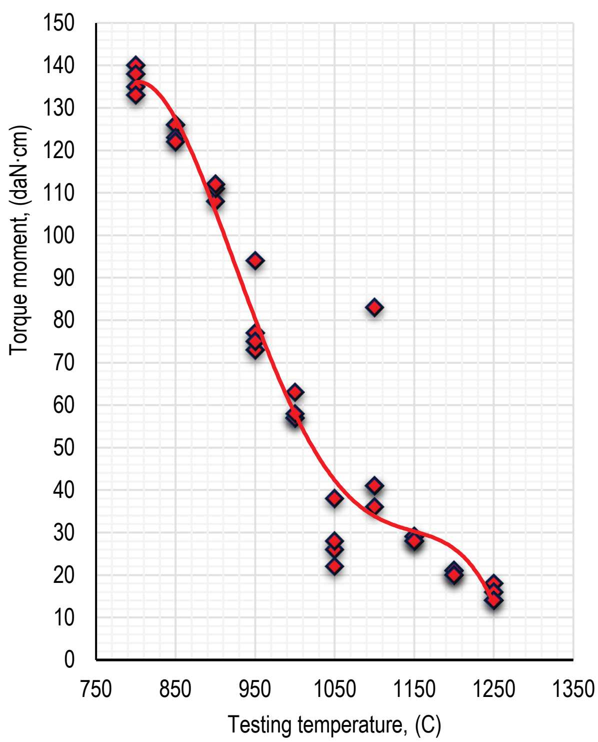

Figure 3 Correlations: Testing temperature vs. Torque moment of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C)

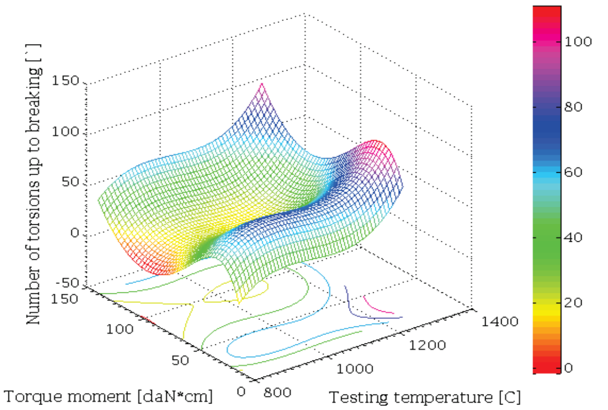

Figure 4 Number of torsions up to breaking vs. Torque moment and Testing temperature of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C) (equation type: $z_1 = a_1 + a_2x + a_3x^2 + a_4x^3 + a_5y + a_6y^2 + a_7y^3 + a_8y^4 + a_9y^5$, standard deviation: $r^2 = 0.9078$)

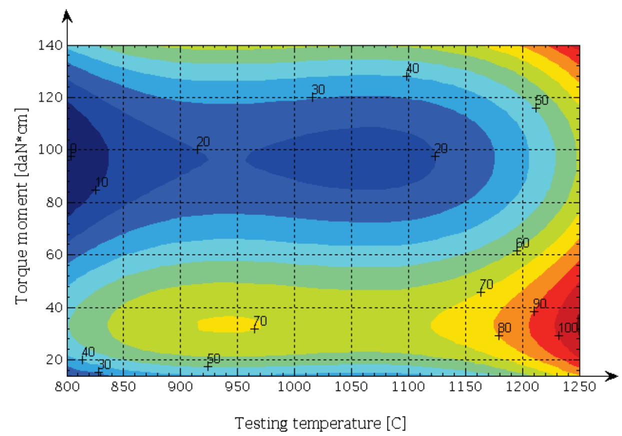

Figure 5 Correlation diagrams for the technological domains' area of deformation resistance: Testing temperature vs Torque moment of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C)

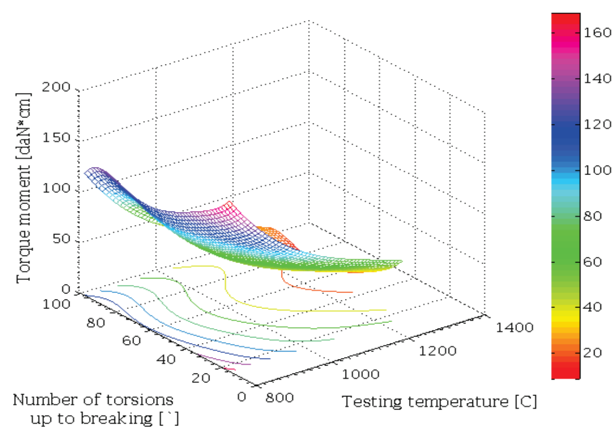

Figure 6 Torque moment vs. Number of torsions up to breaking and Testing temperature of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C) (equation type: $z_2 = a_1 + a_2x + a_3x^2 + a_4x^3 + a_5y + a_6y^2 + a_7y^3 + a_8y^4 + a_9y^5$, standard deviation: $r^2 = 0.9869$)

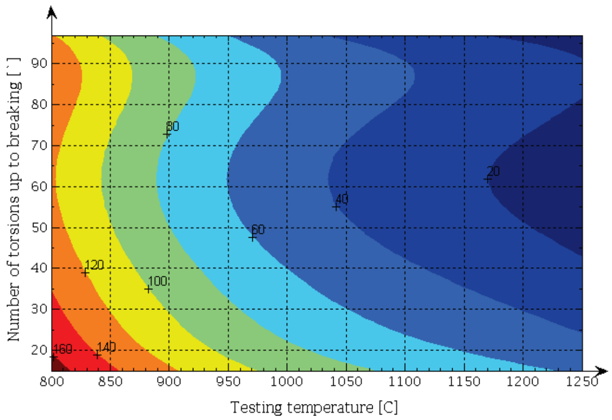

Figure 7 Correlation diagrams for the technological domains' area of plasticity: Testing temperature vs. Number of torsions up to the breaking of ferritic stainless steel (non–hardenable stainless steel, grade X6Cr17), at the experimental heating temperature values (800–1250 °C)

In the graphical representation of the experimental tests' results (Figs. 2–7), we have the following comments and remarks:

- the variations of plasticity and the deformation resistance (expressed by the number of torsions to failure, respectively the maximum torque moment) of ferritic stainless steel (grade X6Cr17) are plotted in the Fig. 2 and Fig. 3;
- the upper limit of the optimum range of heating temperatures applied for deforming the studied steel (ferritic stainless steel, grade X6Cr17) clearly results from the plasticity – temperature diagrams (Fig. 2), being 1050 °C;
- based on the practical skills acquired in the rolling industry, it can be noticed that the heating temperature may be limited due to the risk of excessive grain growth during heating under industrial conditions (phenomenon that does not occur during heating at the torsion machine – and therefore the values given for plasticity at high temperatures);
- regarding the end–heating temperature, the plasticity – temperature diagrams (Fig. 2), for the hot deformation of the studied stainless steel grade (ferritic stainless steel, grade X6Cr17), we have the following experimental values: 800 °C;
- based on the practical experience of the rolling industry, sometimes it is recommended that the last two passes (processing stages of rolling) be carried out at temperatures below 800 °C, for the completion of granulation;
- the variation of the torque moment with the heating temperature, as shown in Fig. 3, indicates that the deformation resistance of ferritic stainless steel (grade X6Cr17) generally decreases when the heating temperature increases;
- the regression surfaces of the plasticity and deformability characteristics of ferritic stainless steel (grade X6Cr17), described by the number of torsions before failure, respectively the maximum torque moment, in correlation with the experimental testing temperature (heating in the 800–1250 °C range of temperature), are shown in Fig. 4 and Fig. 6;
- these regression surfaces (expressed by the equation type: $z = a_1 + a_2x + a_3x^2 + a_4x^3 + a_5y + a_6y^2 + a_7y^3 + a_8y^4 + a_9y^5$, having standard deviations $r^2 = 0.9078$, respectively $r^2 = 0.9869$) can be plotted in Fig. 5 and Fig. 7, and interpreted as correlation diagrams for the deformability characteristics (for the technological domains' area of deformation resistance – Fig. 5, respectively for the technological domains' area of plasticity – Fig. 7), which are typical for ferritic stainless steel, grade X6Cr17;
- the knowledge related to the steel's deformability characteristics (deformation resistance and plasticity) have for the technologist, as well as for the researcher, a great practical significance. The knowledge of the technological domains' area of plasticity and of deformation resistance is very important in the rolling practice because they are important elements in establishing a correct technological rolling process;
- the results of the hot torsion testing of ferritic stainless steel (grade X6Cr17) show that the resistance to deformation increases at deformation speed, being dependent on the nature of the stainless steel and the temperature, while the resistance to deformation decreases with a rise in temperature.

5 CONCLUSIONS

The choice of the heating regime is currently mostly based on the practical experience of the rolling industry. Therefore, the process of establishing the hot processing technology for these steels is primarily related to the definition of heating conditions, according to their technological characteristics. The indications regarding the variation of plasticity with the temperature, using the hot torsion method, allowed the establishing of the temperature range within which steel plasticity is optimal and in which, in general, it is recommended to perform the entire hot plastic deformation.

The diagrams shown above (Fig. 5 and Fig. 7) show that the hot deformability characteristics of ferritic stainless steel (grade X6Cr17) vary as follows:

- hot plasticity increases when temperature increases in the field of 900–1200 °C.
- starting from 900 °C, they have sufficient plasticity, but the value of the deformation resistance is still high – up to 950 °C.
- it decreases after reaching the range of 1050–1150 °C, when the deformation speed increases. This adverse effect of a high rate of deformation is increased by a rise in temperature.
- the growth dynamic of the plasticity characteristics is continuous, reaching the maximum value at 1150 °C, while reducing the resistance to deformation.

Therefore, we can conclude that an increased level of the deformation temperature increases the plasticity within the

950–1150 °C temperature range and that it decreases the resistance to deformation of these types of stainless steel.

Thus, from the torsion tests carried out to determine the hot deformability, it results that the optimal plasticity of the analysed ferritic stainless steel (grade X6Cr17) is found within the temperature range of 950–1200 °C, preferably within the range of 1000–1150 °C.

Acknowledgement

The laboratory equipment used to study the stainless steel deformability by hot torsion is subject to a patent registered with the State Office for Inventions and Trademarks (OSIM–Romania) under the number 439/17.05.2010, entitled "Equipment adapted for experimental determination of the resistance to thermal fatigue of samples placed tangentially on the generator of support discs", No. 54/2011. Additional information about the equipment (description, method, pictures etc.) are available in the studies [11], [12] and [16], according to the below–presented reference list.

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Professional paper

Technical Problems of Industrial Buildings Adaptation - Case Study: "Artist's Alley" in Zielona Góra

Beata Nowogońska

Abstract: The adaptation of post-industrial building allows for solving problems connected with the protection of relics and is useful in the process of providing order to the cultural landscape. However, the adaptation of historic buildings is associated with many problems. At the same time, the conservation, architectural, construction, technological requirements and the investor's ideas must be met. Meeting all conditions at the same time is a difficult task, but possible. The change in the way that a historic building is used requires a series of preliminary studies of the building to be carried out. The article presents the results of the diagnosis of the technical conditions preceding the adaption of a former factory in Zielona Góra.

Keywords: adaptation; adaptive reuse; historic buildings; the protection of cultural heritage; the Venice Charter

1 INTRODUCTION

In the modern-day world, the protection of cultural heritage is connected with the needs of the civilization. Adaptations of historic buildings are made to modern needs. The historic buildings are in use today [1]. The modernization and adaptation of historical objects is the result of ever-changing human needs [2]. Adaptations of historic buildings are the subject of many scientific studies. For example in [3] was evaluates the compatibility of the adaptive reuse of heritage buildings in Egypt. In paper [4] proposing a multicriteria decision aiding approach for ranking adaptive reuse strategies of cultural heritage. The paper [4] focuses on the potential reuse of nine different abandoned buildings located in an industrial valley in the North-West of Italy, with a strong presence of wool and silk factories starting from the 18th century. An overview of the various problems is provided in the conference materials [5]. There are many problems associated with the adaptation of historic buildings. There is a conflict of interest between preserving heritage values and progressing on a sustainable urban project [6].

Dynamic changes taking place around the world and technological advancement are completing the guidelines of the Venice Charter [7]. General assumptions regarding the different approaches to handling relics of course remain. The rules of fully respecting the original substance or choosing solutions which do not harm the object are always current. The rule of minimal interference calls for maintaining form and substance, however it does not exclude introducing contemporary elements. These elements may not distort the historical content [8]. A following rule regarding the clarity and distinctiveness of the insertions also allows for contemporary additions. Adapting post-industrial objects in residential areas for modern-day uses has become something of a trend [9]. The beauty of a historical building, however, has made it so that the changes carried out in the object are small [10]. The introduced novelties are essentially fitted into the existing architecture [11]. The needs of civilizational development as well as spatial changes [12] of cities have made for a trend of adapting post-industrial buildings to serve modern-day service needs [13]. Buildings derived from past centuries continue to be in use, most often being flats, and the current functional standards do not destroy the historic fabric [14].

2 ADAPTATION HISTORIC BUILDINGS - COMBINING PROBLEMS

The topic of adaptation of historic buildings is connected with many problems. At the same time, the following requirements must be met: conservation, architectural, structural, technological and investor's suggestions. Meeting all conditions at the same time is a difficult task, but possible. First of all, the guidelines of the Venetian Charter must be preserved. Historical objects are a reminder of the past and care must be taken to preserve them for future generations. The rescue of unused historical buildings is to adapt them to modern purposes. Today's post-industrial buildings cannot fulfil their original functions mainly due to their small cubic capacity for modern industrial technologies. Moreover, with the development of the cities, these buildings have remained located in the middle of the city, and modern industrial halls with machines compatible with technological progress are located on the outskirts of cities. The best solution for preserving historic post-industrial buildings is to change the way they are used. Very often in post-industrial buildings today flats, shopping malls or cultural purposes are built.

According to the guidelines of the Venetian Charter [2], further use of a historic building can be changed for socially useful purposes. However, it must not entail changes in the layout and decoration of the building. Architectural details, painting and sculptural elements are part of the monument and cannot be separated from it. New utility functions must be such that they do not destroy history. All architectural designs and construction works must be based on respect for the original substance. However, the Venetian Charter is not so strict. It allows modern architectural, structural and technological solutions in exceptional situations, but only when they are necessary. However, new solutions must differ from the original in order not to falsify history.

3 CASE STUDY - "ARTIST'S ALLEY" IN ZIELONA GÓRA. DESCRIPTION OF BUILDING

The building at Fabryczna 13 B comprises three interconnected parts. The first segment, facing Fabryczna Street, contains 2-storeys and a basement; this section is in use and not subjected to adaptation (Figs. 1 and 2). The second part is a one-storey building with a basement (Figs. 3 and 4). The third part is a single-storey extension.

Figure 1 Elevation facing Fabryczna St. (first section) prior to adaption

Figure 2 Elevation facing Fabryczna St. (first section) after adaption

The entire building is a mirror image of the building located on Fabrycza 13 A. Between these neighbouring buildings is an inside square, which can be entered from Fabryczna street through a ornamental gate and two pedestrian gates.

The building was constructed in 1870 in place of wine gardens belonging to the trader Theodor Tobias, and, at the time, belonged to the Lower Silesian Financial Association - the former bank of the Forster family. At first, it was not a classical warehouse, but rather a storehouse of semi-finished products being transported to the Forsters' factories. The main factory owned by the Forsters' was located on what is today Wrocławska Street, and the warehouse also serviced three cooperating companies on Fabryczna St. However, in 1873, the financial group went bankrupt and the warehouse was taken over by the banker Boas Laskau. In 1905, Carl Eichmann opened a weaving mill in the former Forster building. Beginning in 1928, the building functioned as the warehouse of a German Consumer Cooperative from Żagań. After the war, the agricultural and retail cooperative stored vegetables and fruit there. Over the following years, the buildings served as a warehouse for the Społem Cooperative. In 1998, the building suffered a fire, during which the ceiling over the ground floor and fragments of the roof burnt down, while the remaining construction elements were covered with soot. The old un-plastered factory walls gave the place an incredible atmosphere [15].

Figure 3 Southeast elevation of building (second part) prior to adaption

Figure 4 Southeast elevation of building (second part) after adaption

The main building (first and second part), is a two-storey masonry brick structure situated at the end of the street, with a full basement and usable attic. The ceilings over the basement and ground floor are of a timber structure, supported by two rows of brick columns at the level of the basements, and wooden columns at the ground floor level. The roof structure comprises a timber queen post truss, which forms a gable roof covered with bituminous paper laid on roof boarding. The front elevation of the building is highlighted by an axial projection (avant-corps) with a step-like peak. Above the window openings are arched and flat brick lintels, as well as lintels made of steel profiles which were added later. The facade of the building is segmented with pilasters and covered in plaster. The timber window frames are of the double casement type. In the period before the war, a single-storey hall was added on to the western part (third part). The building is of masonry brick construction, covered by a flat roof supported by two rows of reinforced concrete columns. The windows are of wooden box-type with lintels made of steel sections.

4 MAIN ASSUMPTIONS OF THE ADAPTATION

The basements (in the second part) are planned to be adapted into a winery with a supply base. A tasting room for 60 people has also been designed, along with a preparation (changing) room, cloakroom, warehouses and sanitary facilities. On the ground floor (second part), there will be a cabaret hall capable of holding 80 people, a warehouse, sanitary facilities and a set out office section [16] (Fig. 5). The first floor (second part) is planned to be adapted into artistic workshops. In the single-storey extension (third part), a dance school has been designed - a dance hall for 30 people, changing rooms along with a sanitary facilities, an office and toilets [16] (Fig. 5).

The investment covers carrying out renovation works connected with exchanging a fragment of the wooden ceiling to one that fulfills fire safety requirements, some of the elements of the roof truss structure, the complete replacement of doors and windows, the roof cover, all installations and finishing elements. A new stairwell, a different layout of partition walls and outside stairs have also been designed.

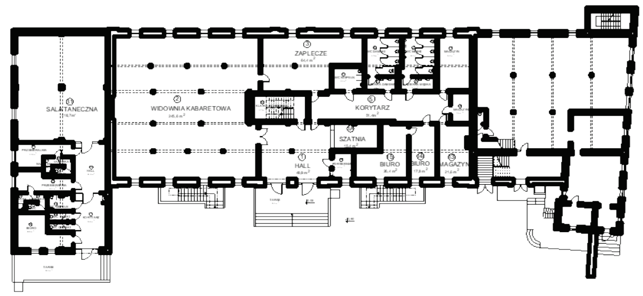

Figure 5 Floorplan of ground level according to the adaptation project

Table 1 Summary of technical problems and their solutions

Problem technical	Characteristics	Solution	Effect
The foundation footings do not meet the requirements set out by standards (Fig. 6)	The foundations under the outside walls are built as brick continuous strip footing laid in cement-lime mortar, underneath columns as brick foundation footings. The cross-sections of the strip foundation measuring 70 x 40 cm, and of footings 60 x 60 x 40, 90 x 90 x 40 cm	Underpinning was planned for some of the footings, and strengthening for others.	Compliance with standard conditions
Destroyed wooden staircase	Degree of technical wear of stairs 100 %	In accordance with fire safety requirements, an internal reinforced concrete stairwell connecting the ground floor with the upstairs was designed. A new reinforced concrete strip foundation has been designed under this structure.	New staircase
The upstairs walls required repair works involving the replacement and filling in of missing bricks.	The existing walls are made of full fired brick laid in cement-lime mortar, plastered on both sides. The thickness of existing walls at the level of the basement is 75 cm, ground floor - 60 cm, first floor - 45 cm, and 73 cm throughout the entire height of walls in the avant-corps section.	Thermal insulation of external walls was planned, as well as making new window openings in such a way that referred back to the original form of the building; some of them were enlarged, others bricked-up.	Insulation of walls, execution of building façade
The existing partition walls	The existing partition walls were made of insulating board	In an effort to adapt the building to the new function, all partition walls were taken apart.	The new walls in the basement were made of full fired brick measuring 12 cm in thickness laid in cement-lime mortar; on the ground floor and first floor, the partition walls were made of drywall
Cellar interior	Missing brick and mortar	Plaster was removed from the existing outer walls of the basement as well as the brick columns, filling areas of missing brick and mortar.	A new cellar
Damaged wooden ceilings	The basements and ground floor were covered with a bare beam ceiling, and thus the timber structure was protected against decay.	Thermal insulation was also carried out using mineral wool	In the fire protection zone, the wooden ceiling was replaced by a joist ceiling of the teriva.
The existing roof is of a timber, gable structure with a slope of 31%, covered by bituminous paper laid on roof boarding, lacking any thermal insulation.	The queen post roof truss with posts in the knee wall remains unchanged (Fig. 7)	The rafters and angle braces were replaced, while the remaining elements cleaned from dirt and soot.	Thermal insulation of mineral wool, replacement of the roof cover, a vapor barrier and finishing the attic with drywall on metal frame were planned and carried out.

5 TECHNICAL PROBLEMS

There were many technical problems during the adaptation. Some of the building's elements were subject to technical wear and tear and had to be reinforced or replaced with new ones. Besides, there were many other problems, e.g. the anti-smoke regulations required the staircase structure to be changed to reinforced concrete, and it was possible to meet the current requirements of thermal standards after the building was insulated. The technical problems are presented in Tab. 1.

Figure 6 Existing brick foundation footings under some of the posts

Figure 7 Queen post roof truss structure during renovation works

Before assuming works, conclusions regarding the technical possibilities of adapting the building were set out. The technical state of the structural elements of the building was assessed as good and strengthening was not required. The change in the designated use and service function of the building also do not have an influence on a change in the technical condition of the building.

6 DISCUSSION

The biggest problem concerning the adaptation of a post-industrial building for serving cultural purposes were not technical issues but those connected with the new service function. Changing the flat roof, strengthening, underpinning foundations, thermal upgrading - these are all typical tasks during such renovation works. Defining the service function proved to be a challenge, thus introducing new functions and corrections to the appearance of the building so as not to lose its initial post-industrial nature but, at the same time, fulfil the expectations of both the investor as well as the appropriate technical requirements. For this reason, the window axes on the ground floor level were shifted, the formerly bricked-over second entrance was recreated, and the layout of communication links changed.

The work of a building engineer is one of an interdisciplinary nature. As one can see, it sometimes also has to influence a change in the appearance of the building so that it reconciles aspects of form, function, structure and technology.

The adaptation of historic buildings to serving modern-day functions does not hold economic rationale, but it does improve the image and esthetics of urban space while fully respecting material cultural heritage [17]. The revitalization of Fabryczna St. will liven up this part of the city, returning it to its inhabitants [18]. In this way, the building at Fabryczna 13 B, as well as all historical buildings subjected to renovation works, are saved from further devastation and, at the same time, rediscovered once again.

7 CONCLUSION

The revitalization of Fabryczna Street in Zielona Góra has been taking place for the past few years. The process was commenced by the adaptation of one of the past factories of the textile industry located on Fabryczna No. 14. Next, lofts were created in another post-industrial building No. 17. Currently, renovation works connected with adapting building No. 13 B for culinary-recreational functions, which is to be named "Artist's Alley" along with its surroundings, are being carried out. The adaptation of post-industrial building allows for solving problems connected with the protection of relics and is useful in the process of providing order to the cultural landscape.

Notice

The paper will be presented at PBE2020 – International Scientific Conference "People, Buildings and Environment 2020". The 14th conference will be held in the Rožnov pod Radhoštěm city, the Czech Republic, from 7 to 9 October 2020. The paper will not be published anywhere else.

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Categorization of paper

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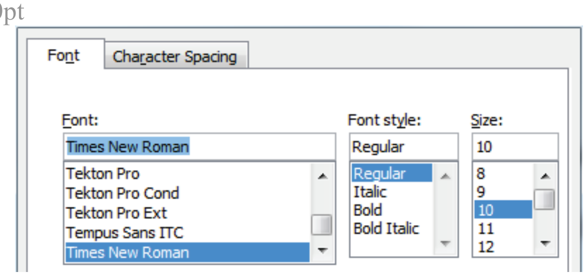

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$$\cos\alpha + \cos\beta = 2\cos\frac{\alpha+\beta}{2}\cdot\cos\frac{\alpha\text{-}\beta}{2}, \tag{2}$$

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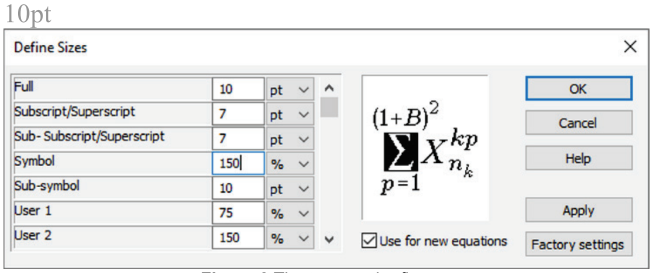

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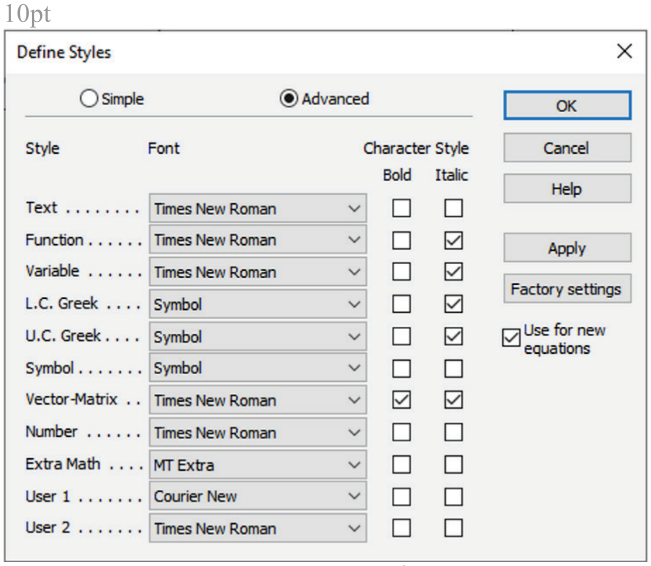

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