

Reorthogonalization Methods Revisited

Csaba J. Hegedüs

Eötvös Loránd University, Dept. of Numerical Analysis
1117 Budapest, Pázmány P. sétány 1/C
hegedus@numanal.inf.elte.hu

Abstract: New theoretical background of Parlett-Kahan's "twice is enough" algorithm for computing accurate vectors in Gram-Schmidt orthogonalization is given. An unorthodox type of error analysis is applied by considering lost digits in cancellation. The resulting proof is simple and that makes it possible to calculate the number of accurate digits after all reorthogonalization steps. Self improving nature of projection matrices is found giving a possible explanation for the stability of some ABS methods. The numerical tests demonstrate the validity and applicability of the theoretical results for the CGS, MGS and rank revealing QR algorithms.

Keywords: twice is enough, Gram-Schmidt with reorthogonalization, self-improving nature of projections, ABS methods, rank-revealing QR.

1 Introduction

A new theoretical background of Parlett-Kahan's "twice is enough" algorithm for computing accurate vectors in Gram-Schmidt orthogonalization is given in this paper. To this aim Rutishauser's control parameter [20] – here called η – is used to decide if

- i) some digits are lost, or
- ii) the new vector to be processed is linearly dependent of the current base numerically, that is, up to machine precision.

Originally, the "twice is enough" algorithm was given for a one-vector projection, however, it works also for parallel multi-vector projections as in classical Gram-Schmidt (CGS). A useful by-product of our analysis is that an estimate for the number of accurate digits can be given in the course of the computation. That can be especially helpful when one has to decide linear dependence e.g. in pseudoinverse calculations.

When orthogonalizing numerically, one may have to face the problem, that the resulting vectors are not orthogonal to each other up to machine precision. The reason

can be attributed to rounding errors, however, cancellation errors are behind the phenomenon. In fact, the process of orthogonalizing two vectors is subject to cancellation errors if the vectors have nearly the same length and direction, in other words, their difference is small.

Wilkinson in his books [23], [22] already considered the problem of losing orthogonality and he identified the main cause as the presence of cancellation. In [22], pp. 382-387, he considered reorthogonalization in conjunction with the Arnoldi process. His numerical example showed that one reorthogonalization step was enough to get orthogonality up to machine precision.

Rice [19] and Hoffmann [17] did extensive numerical experimentations to find, how many reorthogonalization steps are needed. Hoffmann formulated the conjecture that one reorthogonalization step is enough for both – classical (CGS) and modified (MGS) Gram-Schmidt algorithms. On the other hand, Rice found that sometimes multiple reorthogonalizations were needed. For early theoretical investigations, see Daniel *et al.* [14] and Abdelmalek [2].

Parlett and Kahan [18] considered orthogonalization to one vector and gave their "twice is enough" algorithm. Having supposed that the starting vectors were accurate, they supplied an error analysis showing that two orthogonalization steps are practically enough to get a new accurate orthogonal vector.

The Parlett-Kahan (PK) algorithm is based on the following orthogonalization step. Let z be the vector to be orthogonalized to y . Then let

$$p = \left(I - \frac{yy^T}{\|y\|^2} \right) z = \text{orth}(y, z) \quad (1)$$

denote the exact orthogonalization of z , where the 2-norm or Euclidean norm is used from now on. In reality, we have only a numerical approximation to p , say x' . Let the error $e' \equiv x' - p$ satisfy $\|e'\| = \varepsilon \|z\|$, where ε is a small number, practically close to the machine precision unit ε_M and let κ be any fixed value in the range $[1/(0.83 - \varepsilon), 0.83/\varepsilon]$ then the "twice is enough" algorithm of Parlett and Kahan is given by

The PK algorithm

Calculate $x' = \text{orth}(y, z)$, where orth is given in (1).

Case 1: If $\|x'\| \geq \|z\| / \kappa$ accept $x = x'$ and $e = e'$. otherwise compute

$$x'' = \text{orth}(y, x')$$

with error

$$e'' \equiv x'' - \left(I - \frac{yy^T}{\|y\|^2} \right) x'$$

satisfying $\|e''\| = \varepsilon \|x'\|$ and go to Case 2

Case 2: If $\|x''\| \geq \|x'\|/\kappa$ accept $x = x''$ and $e = e'' - p$.

Case 3: If $\|x''\| < \|x'\|/\kappa$ accept $x = 0$ and $e = -p$.

Theorem 1. *The vector x computed by the algorithm ensures that $\|e\| \leq (1 + 1/\kappa)\varepsilon\|z\|$ and $|y^T x| \leq \kappa\varepsilon_M\|y\|\|x\|$.*

For proof, see [18].

Remark 1. *Observe that if x' is machine zero then Case 2 will accept a zero vector. The equality sign should be moved to Case 3.*

One-vector projections are used in the MGS algorithm [4], [5], hence orthogonalizing twice solves the accuracy problem for MGS that is a sequential algorithm.

For the well parallelizing CGS the question if the "twice is enough" algorithm works well, was answered positively by Giraud et al [9], [10]. It is still worth mentioning that for computing the reduced norm of the orthogonalized vector, Smoktunowicz et al [21] suggest to compute $\sqrt{c^2 - a^2}$ by replacing the terms under the root sign with $(c - a)(c + a)$. They also supply an error analysis for justification. We shall compare this method with the standard computation and also, with another method by using trigonometric functions.

For a recent application of reorthogonalization in the Golub-Kahan-Lanczos bidiagonalization, see the paper by Barlow, [3].

The schedule of this paper is the following: We present our considerations in the next Section: conditions for reorthogonalization and a new short general proof.

The other sections are concerned with the comparison and testing of the new re-orthogonalization algorithms.

It is also assumed that rounding errors and cancellation errors are such that there are some accurate digits in the computation.

2 Conditions for reorthogonalization

The "twice is enough" algorithm will be reformulated here from the point of view of cancellations. The theorem is stated for orthogonalizing with respect to a subspace in one step, such that the generalization given by [10] is also covered. The improvement of orthogonality is stated and we give a new short proof. Our analysis assumes that there are some accurate figures in the computation. The section is ended by accurate digits estimation and numerical experimentation.

2.1 The cancellation phenomenon

Cancellation happens if two numbers are nearly the same and they are subtracted from each other. For example, assume a 6-digit decimal arithmetic and compute: $126.426 - 126.411 = 0.015$. It is seen, the first four digits are lost, and the result,

if normalized, has the form: $0.150000 \cdot 10^{-1}$. Now the question is, how can we interpret the accuracy of the result. If there were 10 digits and the further 4 digits – which are not seen here – are the same, then the result is accurate to 6 decimals. If the missing four digits were not the same, then we have accuracy only for two figures. As seen, the number of accurate digits may range here from 2 to 6.

Wilkinson in his book [23] adopts the optimistic picture that accuracy is not lost, and that makes it possible to introduce the error postulate for floating point operations:

$$\text{fl}(a \circ b) = (a \circ b)(1 + \varepsilon), \quad |\varepsilon| \leq \varepsilon_M,$$

where \circ is any of the four arithmetic operations and ε_M is the machine precision unit. Higham [16] (Sec. 1.7) gives an example of computing $(1 - \cos x)/x^2$ for $x = 1.2 \cdot 10^{-5}$ when there are 10 significant figures. The result is clearly in error and another formula is suggested to avoid subtraction. But such tricks are not always applicable.

Considering the relative precision, he states that "subtractive cancellation brings earlier errors into prominence". Without the postulate above, the error analysis of numerical algorithms can not be done or it can be overwhelmingly difficult. As a rule of thumb, the postulate is accepted and programmers are advised to avoid cancellation as much as possible.

In the following we shall consider cancellation as is and we shall be looking for the number of accurate figures.

Let the scalars α, β be nonzero and nearly the same. When subtracting, the cancellation can be characterized by the ratio

$$\eta = \frac{|\alpha - \beta|}{\max(|\alpha|, |\beta|)}. \quad (2)$$

If $\eta > 0.5$ we may say that there is no cancellation of binary digits, while in the case of $\eta < 10^{-\rho}$ – where ρ is the number of accurate digits – we say that the two numbers are the same to computational accuracy. Although 15 decimal digits are assumed in double precision computation, we should take into account that usually the last 2-3 digits are uncertain due to rounding errors. Therefore a practical choice for ρ is $\rho = 12$. We may lose digits by cancellation if the condition

$$10^{-\rho} \leq \eta < \eta_{\max} \quad (3)$$

holds, where $\eta_{\max} = 1/2$ may be chosen. The *worst case is assumed always*, therefore the number of lost decimals is estimated by $-\log_{10} \eta$. This value is 4.06... in the above example.

As a consequence, the number of accurate digits after subtraction is

$$\gamma = \rho + \log_{10} \eta \quad (4)$$

and the error of the difference $|\alpha - \beta|$ is $10^{-\gamma} |\alpha - \beta|$. Similarly, the error of η can be given by $10^{-\gamma} \eta$.

We shall see in the sequel that ρ – the number of accurate digits without cancellation – can be estimated after a reorthogonalization step.

2.2 Cancellation in Gram-Schmidt orthogonalization

Here we consider one step of Gram-Schmidt orthogonalization.

Introduce $Q = (q_1, q_2, \dots, q_{k-1}) \in \mathbb{R}^{n \times (k-1)}$ and $a \in \mathbb{R}^n$ be known and accurate. Vector a is orthogonalized to the subspace spanned by the orthonormal columns of matrix Q in one Gram-Schmidt step

$$\theta_k q_k = (I - QQ^T)a, \quad (5)$$

where q_j -s are normalized that is, $\theta_k = \|(I - QQ^T)a\|_2$ holds and the subscript for the 2-norm will be omitted in the sequel.

Comparing the subtraction here with the case of cancellation from the previous subsection, θ_k of (5) refers to $|\alpha - \beta|$ and we identify $\max(|\alpha|, |\beta|)$ as the norm of $\|a\|$ because we may expect $\|Q^T a\|$ not larger than $\|a\|$. Hence we are led to the formula of

$$\eta = \frac{\theta_k}{\|a\|}, \quad (6)$$

a computable value for which (3) can be checked.

If $\eta \geq \eta_{\max}$ then q_k is accepted, else if $\eta < 10^{-p}$ the vectors $a, q_1, q_2, \dots, q_{k-1}$ are considered linearly dependent – at least computationally – such that another vector a should be chosen.

Otherwise, if (3) is fulfilled then redo orthogonalization for q_k :

$$\hat{\theta}_k \hat{q}_k = (I - QQ^T)q_k. \quad (7)$$

The next theorem states that at most two orthogonalization steps are enough to get a new orthogonal vector to computational accuracy. The phenomenon was already observed by Wilkinson [22] and later formulated as a conjecture by Hoffmann [17]. Parlett in his book [18], with a reference to Kahan gave a proof for $k = 2$, (orthogonalization to one vector). Later Giraud *et al* [9], [10] gave proof for any k . We show here that the proof is much simpler using the above picture.

Theorem 2. *If there are accurate digits in the computation, then one may expect the fulfillment of condition $\eta_{\max} \leq \eta$ after the second orthogonalization step at most. The largest choice of such η_{\max} is $1/\sqrt{2}$ to fulfill the condition. Hence the resulting vector \hat{q}_k can be considered orthogonal to q_1, q_2, \dots, q_{k-1} up to computational accuracy if η_{\max} is not less than 0.5.*

Proof. Before giving the proof, recall that poor orthogonality after the first step is attributed to cancellation. The second orthogonalization step – if needed – may be interpreted as orthogonalizing the emerging error vector with respect to the columns of Q . Taking the square of the norm in (5), we get

$$\theta_k^2 = a^T (I - QQ^T)a = \|a\|^2 (1 - \|Q^T \tilde{a}\|^2), \quad (8)$$

where the normed vector $\tilde{a} = a / \|a\|$ is used. Denote the angle between $\mathcal{R}(Q)$ (range of Q) and a by $\angle(\mathcal{R}(Q), a)$, then we get the formula

$$\eta = \sin \angle(\mathcal{R}(Q), a) \quad (9)$$

that can be obtained by considering the rectangular triangle with hypotenuse $\|\tilde{a}\| = 1$, and legs $\|Q^T \tilde{a}\|$ and $\eta = \sqrt{1 - \|Q^T \tilde{a}\|^2}$, this latter is the distance of \tilde{a} from $\mathcal{R}(Q)$, see Figure 1. For more detailed informations on subspace angles, see [8]. A short proof for the smallest angle between a vector and a subspace can be found in [17].

Now assume $\eta \in [10^{-\rho}, \eta_{\max})$ holds such that reorthogonalization is needed. Then we have to show that after reorthogonalization $\eta_{\max} \leq \eta_r$ will succeed for the new η_r . Indeed, by replacing a with q_k in (5), we get for (9)

$$\eta_r = \sin \angle(\mathcal{R}(Q), q_k). \quad (10)$$

This angle is $\pi/2$ accurately the sine of which is 1. Now it is simpler to estimate $\cos \angle(\mathcal{R}(Q), q_k)$ instead of (10), where the computation is subject to errors. The cosine rule will be used for the almost rectangular triangle and the result is

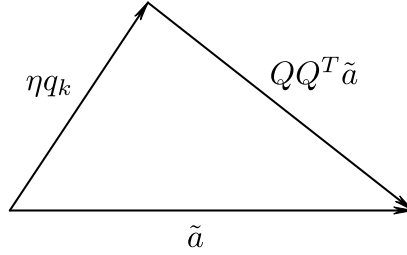


Figure 1
The projection triangle

$$\cos \angle(\mathcal{R}(Q), q_k) = \frac{\eta^2 + \|Q^T \tilde{a}\|^2 - 1}{2\eta \|Q^T \tilde{a}\|}. \quad (11)$$

If there were no errors in the calculation, then the numerator would be zero as it can be checked from (8). Actually we have

$$\cos \angle(\mathcal{R}(Q), q_k) = \frac{\eta^2 - \eta^2}{2\eta \|Q^T \tilde{a}\|} = \frac{\eta - \eta}{2\|Q^T \tilde{a}\|}, \quad (12)$$

where numerator and denominator were divided by η . It was shown earlier that the error of η is $10^{-\gamma}\eta$ and we can assume that \tilde{a} is nearly the same as $Q Q^T \tilde{a}$ in case of cancellation. Therefore $\|Q^T \tilde{a}\|$ is near to 1. We approximate the error of $\cos \angle(\mathcal{R}(Q), q_k)$ by taking twice the error of η in the numerator and replace $\|Q^T \tilde{a}\|$ by 1 in the denominator:

$$\cos \angle(\mathcal{R}(Q), q_k) \approx \frac{2\eta 10^{-\gamma}}{2} \leq 10^{-\gamma} \eta_{\max} \leq \eta_{\max}, \quad (13)$$

as the largest possible value of η is η_{\max} and the smallest value of γ is 0 (all accurate digits are lost). We are looking for an η_{\max} for which the second inequality of

$$\sin \angle(\mathcal{R}(Q), q_2) \gtrsim \sqrt{1 - \eta_{\max}^2} > \eta_{\max}$$

also holds. We have equality on the right if $\eta_{\max} = 1/\sqrt{2} \approx 0.707$. It is easily seen that if $10^{-\gamma}\eta$ with a positive γ is applied under the square root instead of η_{\max} then the inequality on the right is fulfilled even better. That η_{\max} should not be chosen below 0.5 was discussed in the first subsection here. \square

Compare it with $1/\kappa$ that corresponds to our η_{\max} in the PK algorithm. There the possible largest choice is $1/\kappa = 0.83 - \varepsilon$. That is near to the here found $\eta_{\max} = 0.707$. But $\kappa = 100$ is also suggested for less computational works. In that case one agrees to loose roughly two decimal digits of precision and computation to machine accuracy is abandoned. By choosing $10^{-k}/\sqrt{2} = \eta_{\max}$, one allows losing k decimal digits.

On the other hand, the smallest possible choice in the PK algorithm for $1/\kappa$ is $\varepsilon_M/0.83$. It seems too small with respect to our criterion of acceptance.

2.3 Estimating the accuracy of computation

If we repeat orthogonalization then the new η_r can give a method to estimate ρ , the number of accurate digits.

For exact computation $\eta_r = 1$ should hold. We adopt the picture that when reorthogonalization is done, the error vector caused by cancellation is orthogonalized at the second step. The norm of the error vector of q_k can be estimated by $10^{-\gamma}\eta$ after the first step. We have in the second step:

$$\eta_r^2 = 1 - \|Q^T q_k\|^2 = 1 - (10^{-\gamma}\eta)^2$$

because the accurate part of q_k gives zero contribution. Consequently, see also (4)

$$\log_{10} \|Q^T q_k\| = -\gamma + \log_{10} \eta = -\rho - \log_{10} \eta + \log_{10} \eta$$

that is,

$$\rho = -\log_{10} \|Q^T q_k\|. \quad (14)$$

Observe that ρ depends on the step number k , therefore it should be calculated step by step such that

$$\rho_k = -\log_{10} \|Q^T q_k\|. \quad (15)$$

Comparing with the PK algorithm, there $\eta_r < \eta_{\max} = 1/\kappa$ is used for stating zero for the projected vector. Now assume $\rho = 0.4$. The interpretation is that even half decimal digit accuracy can not be assumed after the first projection and that indicates

serious cancellation. Then $\eta_r \approx 0.92$ holds and using $\eta_{max} = 0.707$, the condition in Case 3 is not fulfilled. For this η_{max} the equivalent condition for Case 3 is:

$$\rho \leq 0.1505, \quad (16)$$

where the inclusion of equality was suggested in Remark 1. For smaller values of η_{max} , the upper bound here will be slightly diminishing, but it always remains positive. As seen, the PK algorithms allows the loss of almost all decimal digits for identifying a numerically zero vector.

If rounding errors are not negligible then observe that cancellation makes sense only if it is larger than rounding errors. An estimate for rounding error of a scalar product can be found in [12] :

$$|\delta(y^T x)| \leq 1.01n\epsilon_M \|y\| \|x\|, \quad (17)$$

where n is the length of vectors. For a rounding error analysis of the Gram-Schmidt process, see [2], [4], [5] and [11]. It is seen that for very large n the rounding errors may be so big that there are only few accurate digits, or in pathological cases, $\gamma < 0$ characterizes the situation.

Fig. 2 shows a picture to illustrate the behaviour of ρ . Vector a is orthogonalized to p with optional reorthogonalizing, where the distance of a and p is varying as 10^{-k} , such that k is between 1 and 14. In fact, $a - p$ was chosen to be perpendicular to p . It is seen that orthogonality holds for 16 figures in all cases and the number of accurate digits are diminishing as the two vectors are getting closer. Using a double precision arithmetic, normally one expects that the values in (15) are around 14-15. Smaller values may be considered as indicator for the events of serious cancellation.

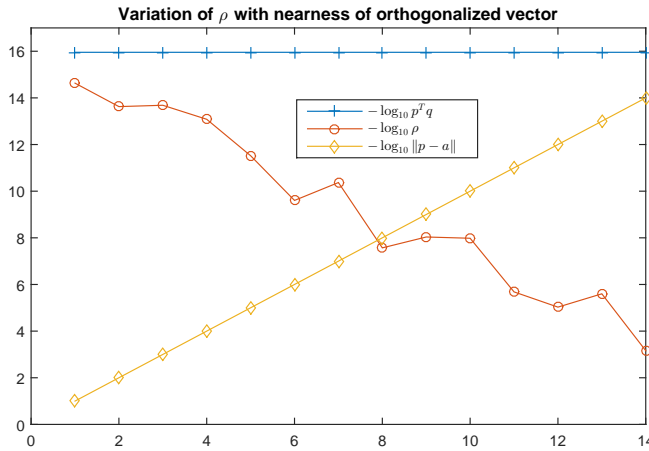


Figure 2
Orthogonalizing nearby vectors

2.4 Numerical experiments

Fig. 3 shows variation of precision in the function of η_{\max} . The matrix is an 80×80 random matrix having entries from $(-1, 1)$ and the computation has been done under Matlab R2014b. The curve with + signs shows QR how well approximates matrix A . The values

$$-\log_{10} \frac{\max |A - QR|_{ij}}{\max |A|_{ij}} \quad (18)$$

are shown in the function of η_{\max} . Similarly, the values

$$-\log_{10} \max |(I - Q^T Q)_{ij}| \quad (19)$$

show the number of accurate digits for Q in the worst case. It is seen, we are below machine accuracy for $\eta_{\max} \leq 0.4$. But there is an improvement to machine accuracy when η_{\max} reaches the value 0.6 which is in good agreement with the theory. That QR serves a good approximate to A even if the orthogonal system is less accurate was already stated in [5].

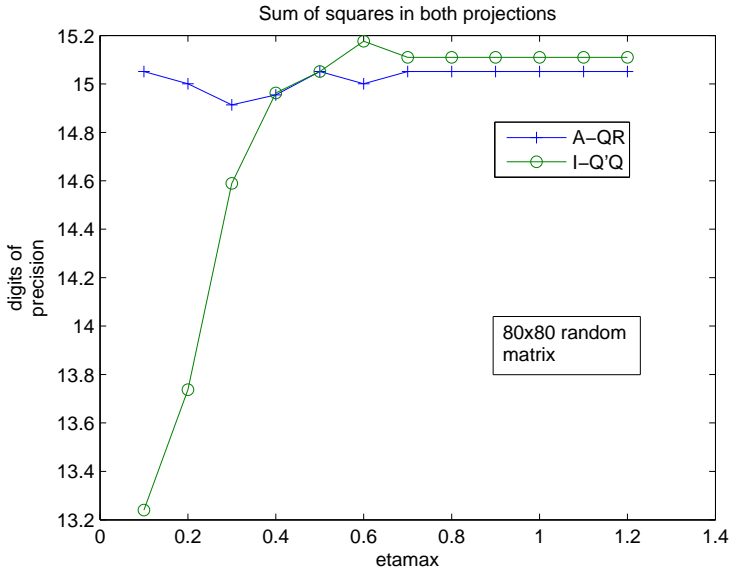


Figure 3
Sum of squares are computed in both cases

For computing θ_k of (5), we have some possibilities.

1) Sum of squares.

Here vector $\theta_k q_k$ is computed by (5) and the norm of the vector is taken by computing sum of squares as in 2-norm calculations. The first and second orthogonalization was computed by this approach in Fig. 3.

2) Difference of squares.

This way of computation uses

$$\theta_k = \sqrt{\|a\|^2 - \|Q^T a\|^2} = \|a\|^2 \sqrt{1 - \|Q^T \tilde{a}\|^2}$$

analysed by Smoktunowicz *et al* [21], where the product form is taken for the difference of squares. The results of this second approach can be seen in Fig. 4 for the same matrix, where computation was done with difference of squares method in the first and second orthogonalization. Quite astonishingly the accuracy is poorer for small values of $\sigma = \|Q^T \tilde{a}\|$, – that is the case for reorthogonalizations – and it occurs more frequently with increasing η_{\max} . The difference of squares method is not always better, in fact, more and more digits of σ are lost in the computation of $(1 - \sigma)(1 + \sigma)$ because of the relatively large value of 1. To check this statement,

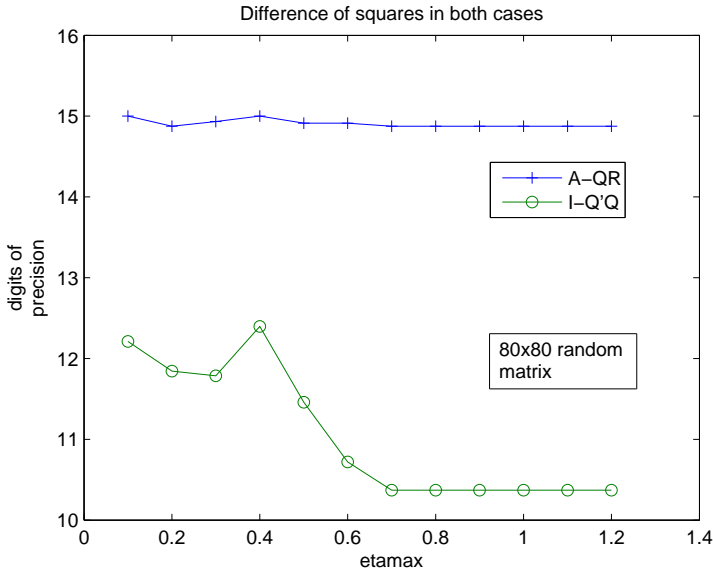


Figure 4
Difference of squares are computed in both cases

we show the results in Fig. 5, where the first approach is applied in the case of reorthogonalization.

3) Trigonometric functions.

A third approach is the use of trigonometric functions. We can use the formulas

$$\beta = \arccos(\|Q^T z\|), \quad \eta = \sin \beta,$$

where $z = \tilde{a}$ in the first step and $z = q_k$ in the second step. But then we get to a similar picture that could be seen in Fig. 4. And changing back to the first approach in the second step will result in the same situation that is shown in Fig. 5.

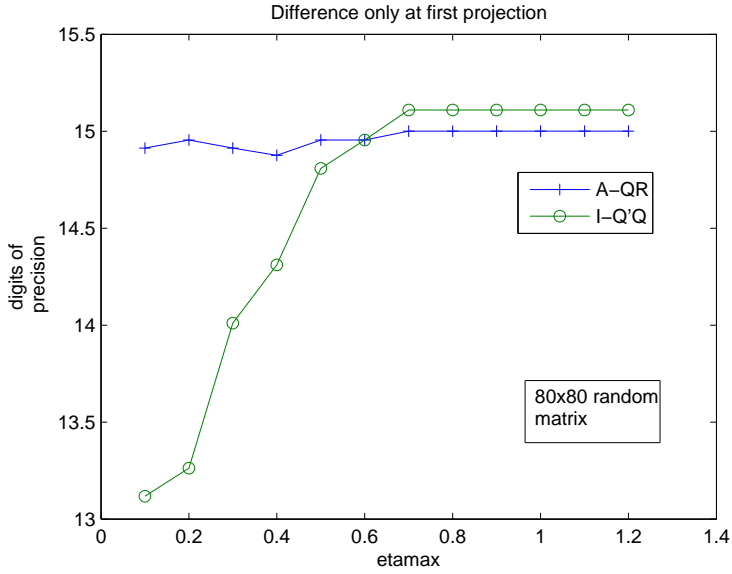


Figure 5
Difference at first, sum of squares in second case

The numerical experimentations have led us to the statement: numerical accuracy will be better using the first approach – compute projected vector and take norm – if $Q^T z$ is very small. This time, when looking into numbers, an additional surprise is that the numerical values of η are very close to 1 such that they may be even larger than 1 – a situation that contradicts to being a value of the sine function. It stresses the belief that rounding errors govern the situation here. Observe that the second and third approach force $\eta \leq 1$, therefore they can not handle the numerical case of $1 < \eta$ so well because division by η is needed for normalization.

2.5 Updating QR-decomposition in reorthogonalization

It still deserves some words how updating of matrix R can be done after the second orthogonalization step. At the first step the k th column was given by

$$\begin{bmatrix} a^T Q & \theta_k \end{bmatrix}^T.$$

In the reorthogonalization step, one applies the projection to $\theta_k q_k$ giving

$$\theta_k(q_k - QQ^T q_k) = \theta_k \eta_r \hat{q}_k,$$

where η_r is the norm of $(q_k - QQ^T q_k)$ such that the resulting vector \hat{q}_k is normed to 1. Now it is seen that the updated k th column of R is given by

$$\begin{bmatrix} a^T Q + q_k^T Q & \theta_k \eta_r \end{bmatrix}^T. \quad (20)$$

It was observed in numerical experiments that updating the nondiagonal column elements in matrix R ruins the quality of QR if there is a large loss of precision after the first orthogonalization step. Because of that updating was allowed only for large enough ρ of 15 in our rank finding program.

2.6 Orthogonal base algorithms

Minor modifications in the PK algorithm were suggested:

- Choose $\kappa = \sqrt{2} \cdot 10^i$ if the loss of i decimal digits are allowed.
- Move equality sign from Case 2 into Case 3.

We are in agreement with other authors that projection into an arbitrary subspace is also allowed.

Another variant of orthogonal base algorithm (OBA) can also be given that reflects the view of this paper. Now all three approaches may be applied for norm calculation in the first phase but for reorthogonalization only the first approach is suggested in accordance with the *Numerical experimentation* Subsection. Chose for ε a nearby value to ε_M and $\eta_{\max} = 0.707$. Assume that $k - 1$ orthogonal vectors are ready, then the k th step can be given by

Algorithm 2. *One step of OBA*

Orthogonalize a_k to the first $k - 1$ columns of Q by (5)
 Compute θ_k by (5) and then η by (6)

```

If  $\eta < \varepsilon$  then act for a linearly dependent vector
  else
    Compute the  $k$ th columns of  $Q$  and  $R$ 
    if  $\eta \leq \eta_{\max}$ 
      Perform reorthogonalization by (7)
      Update the  $k$ th columns of  $Q$  and  $R$ 
    end_if
  end_else
end_if

```

One can also lower upper bound for loosing digits as in the PK algorithm. Projections can be done as in (5) and with explicitly computed matrices.

Another variant may be to apply reorthogonalizing always. There are signs that such an algorithm may show good performance, [7]. However, one should be cautious in that case, see the remark after (20).

3 Some further applications of OBA

First we remark that reorthogonalization may be applied to improve an orthogonal projection that is subject to numerical errors. If it is given in the form of QQ^T that can be considered a Choleski decomposition of a positive semidefinite matrix,

then the steps of OBA give a straightforward procedure to refine a vector q_i in the orthogonal system.

One can also give a quality improvement if the projection is given by a matrix P . Now say, column i should be corrected. Then form the projection

$$\hat{P} = P - \frac{Pe_i e_i^T P}{e_i^T P e_i}. \quad (21)$$

It brings Pe_i into zero: $\hat{P}Pe_i = 0$. Its direction may be corrected by

$$z = Pe_i - \hat{P}Pe_i \quad (22)$$

and then the improved projection can be re-gained by

$$\hat{P} + \frac{zz^T}{z^T z}. \quad (23)$$

Observe that all nonzero columns are eigenvectors of the projection matrix with eigenvalue 1. The eigenvectors with eigenvalue zero can be found in the zero space of the matrix. Taking the powers, the eigenvectors with zero eigenvalue will improve, while the eigenvectors with eigenvalue 1 may be slightly deteriorated, if an eigenvalue is not exactly 1. But we can change to $I - P$ such that the image space and zero space are interchanged. Then by taking the powers of $I - P$ improves the image space of P .

Also, observe that methods intensively using projections such as in ABS methods [1] will consecutively improve the quality of zero space, hence they have a self-improving nature. That explains, why some ABS methods can be unusually stable even in case of pathological matrices.

3.1 Rank revealing QR algorithm with reorthogonalization

Rank revealing by QR (RRQR) decompositions were introduced by Chan [6] and later investigated by many authors. Ch. 5 of [12] gives samples of such orthogonal algorithms. See also [13] for a good account of RRQR decompositions. We do not want to dwell much on such algorithms, our aim here is to show only some applications of repeated orthogonalization.

For rank revealing one permutes the columns of A so that the column having the maximal 2-norm comes first. An easy way of the algorithm is to reorder columns in decreasing order of length at the beginning and then apply QR factorization. A more demanding variant chooses the vector of maximal column norm in the i th step of the remaining projected vectors. Specifically, denote by Q_i the matrix of i orthonormal columns, the corresponding projection matrix by $P_i = I - Q_i Q_i^T$, then choose column $P_i A e_k$ for which $\|P_i A e_k\|$ is maximal among the so far not chosen vectors.

Program GSrank was written for rank revealing. The following choices were applied: $\eta_{\max} = 0.707$ and $\varepsilon = 4\varepsilon_M$. ρ_{out} was computed by (14) and reorthogonalization was done if $\eta < \eta_{\max}$ and $\rho_{out} < -\log_{10}(2\varepsilon_M)$ were satisfied and the current

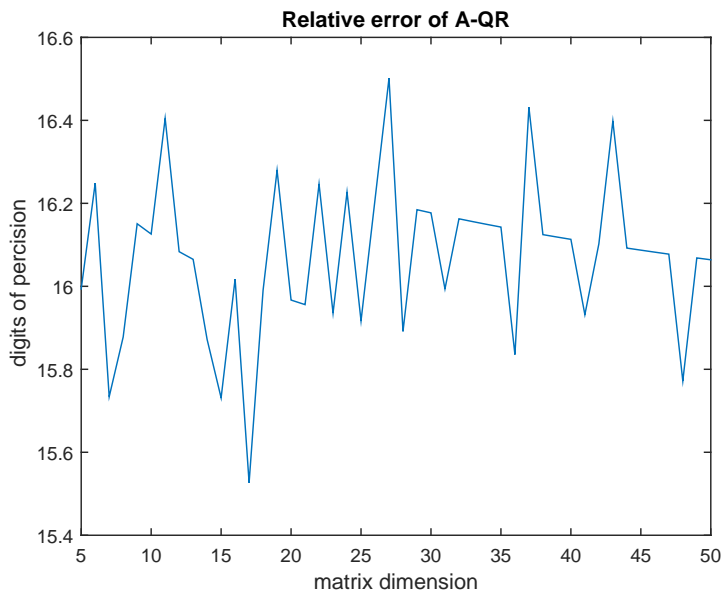


Figure 6
Errors of A - QR for Pascal matrices

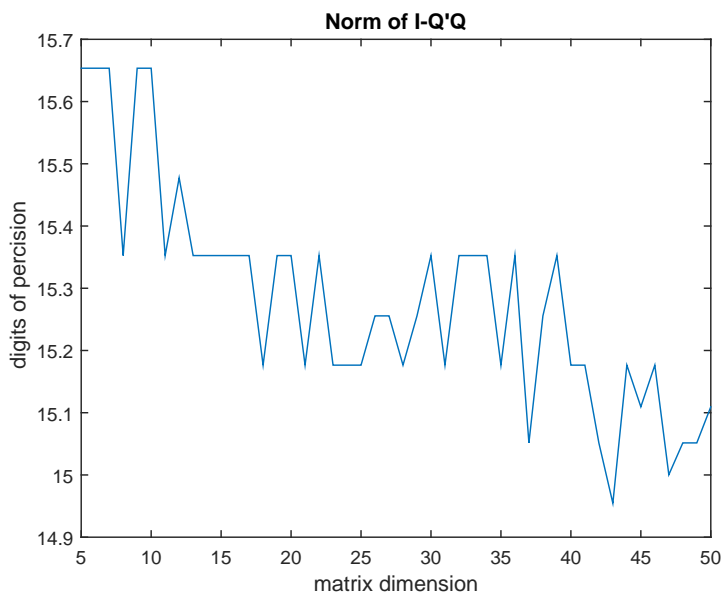


Figure 7
Goodness of orthogonal vectors for Pascal matrices

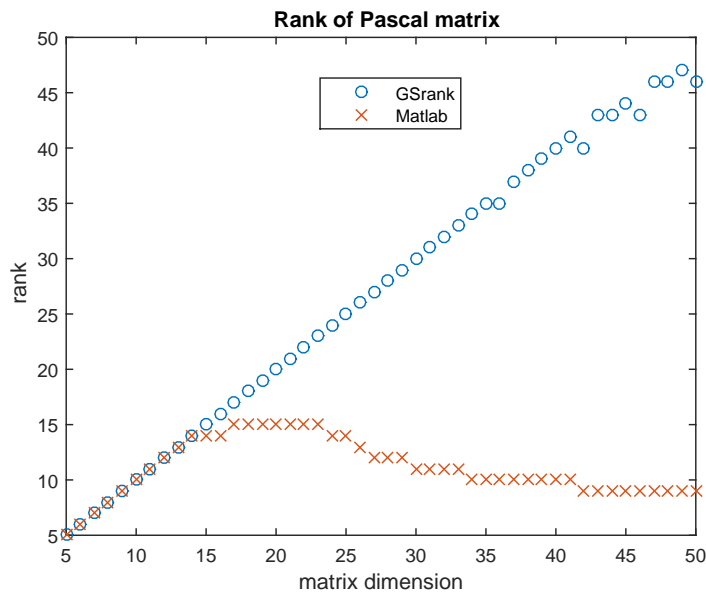


Figure 8
The found ranks of Pascal matrices

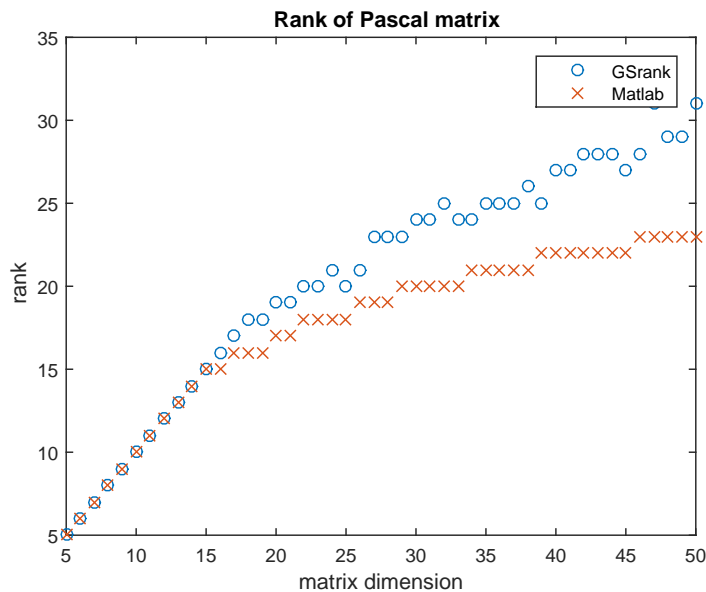


Figure 9
Rank results with normed rows

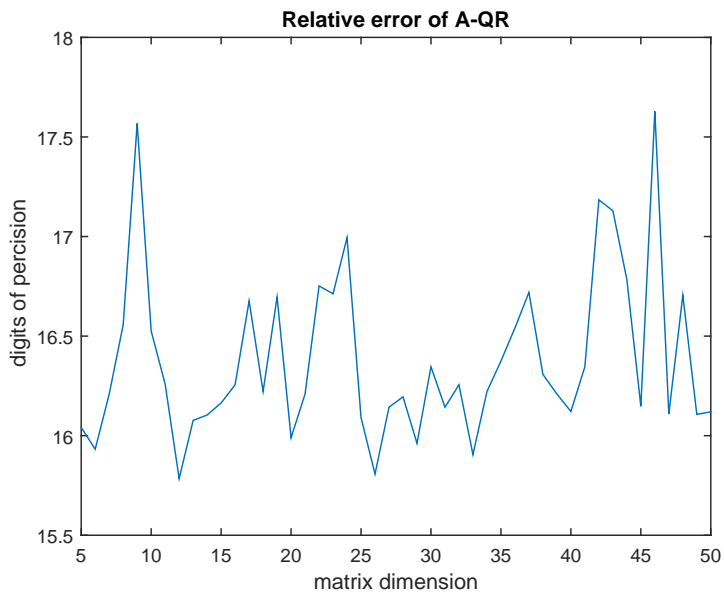


Figure 10
Vandermonde matrices

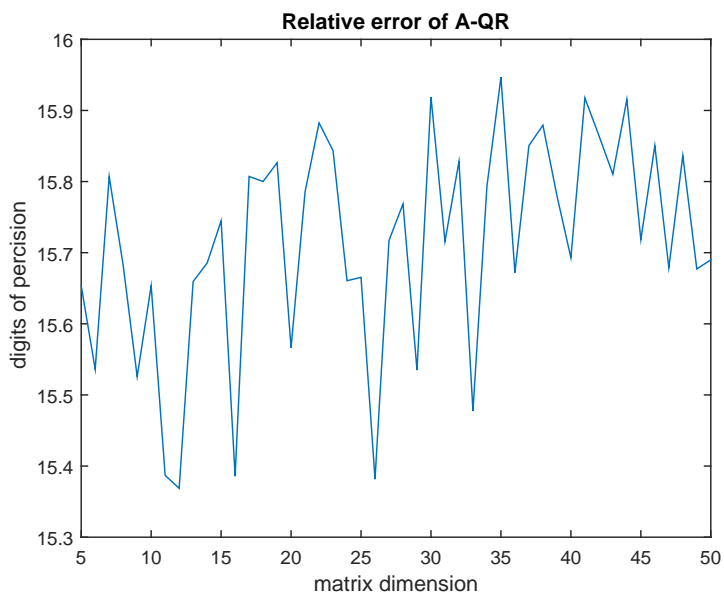


Figure 11
Corrected relative errors for Vandermonde matrices

vector was not considered linearly dependent. The update formula for the non-diagonal column elements of R was allowed only if $\rho_{out} \geq -\log_{10}(\varepsilon)$ had been satisfied. The projection P_i was calculated explicitly.

Such methods are working well for ordinary matrices. It is more interesting to show results for pathological cases. One example is the Pascal matrix that is found in Matlab's collection and can be called by the statement `pascal(n)`. Figures 6 and 7 show the goodness of the factorization for Pascal matrices.

The attentive reader may observe in Fig. 6 that the relative precision can be as large as 16.4 decimal digits, though having a double precision arithmetic, that accuracy is impossible. Formula (18) was applied here. First one might think that it could be attributed to the chosen norm. However, a more probable explanation is the following: The absolute largest matrix element is so large that the next largest one is less by some orders of magnitude. Chances are good that the column having the largest element comes first, or it is among the firstly chosen vectors. As the explicit projection P_i is applied in all steps, then it follows that the direction of such vectors are projected out many times and finally it may happen that the error of some largest elements are machine zero. Then for a more reasonable relative error, only those largest elements should be taken, for which the error is not machine zero. Naturally, a smaller divisor applies in that case. An example for such kind of relative error computation will be shown for Vandermonde matrices.

For Fig. 7, formula (19) was applied. As seen, machine accuracy may be assumed for all Pascal matrices, the condition numbers of which are roughly proportional to 10^{n-1} . The entries in Pascal matrices are exactly representable by machine numbers up to the order of 23. It may be a question that the double precision form of higher order matrices still have rank equal to their size. Such matrices were converted and tested in quadruple precision arithmetic. It was found that all of them have rank equal to their size [7].

The rank results can be seen in Fig. 8 as compared to those of Matlab.

In this example the 35th row was copied into the 45th row in order to test sensitivity. As seen, GSrank performs well, however, there are uncertainties in higher dimensions. Matlab's rank finder suffers if there are numbers very different in their order of magnitude. If all rows are normed to 1, then rounding errors are introduced into matrix data and that leads to another picture. Now Matlab performs better.

The other matrix tested is the Vandermonde matrix with base points $1, 2, \dots, n$. The results are similar to those of the Pascal matrix.

Fig. 10 shows even "better" – but impossible – relative errors for the goodness of QR-decomposition. The remarks previously given to Fig. 6 apply here once again. According to that, a program was written for the relative error such that search for absolute maximal matrix element was done only for entries having a nonzero error. The corrected relative errors in Fig. 11 justify the supposed phenomenon. Figures 12 and 13 show the goodness of the orthogonal base and rank results for Vandermonde matrices.

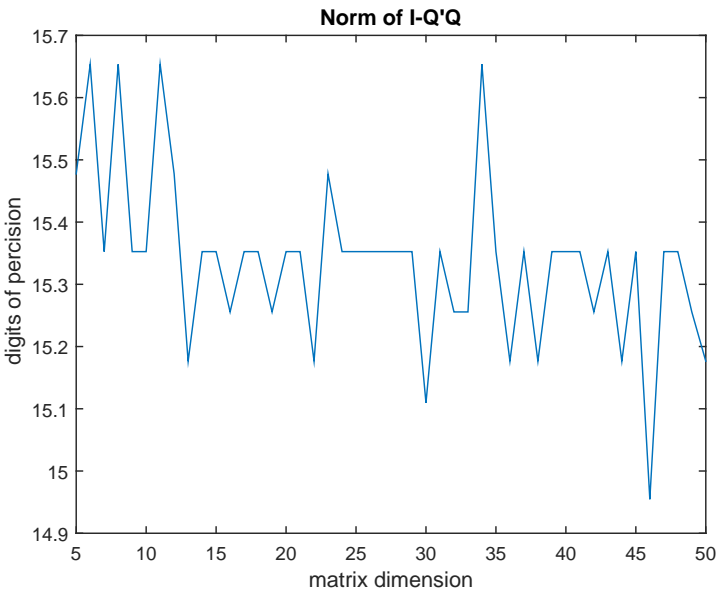


Figure 12
Quality of orthogonal systems for Vandermonde matrices

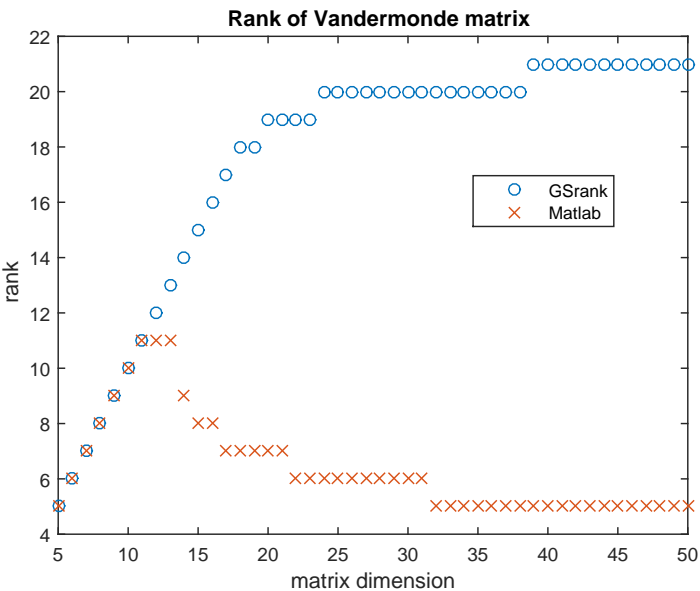


Figure 13
Found ranks of Vandermonde matrices

3.2 Programs to download

For checking and further tests, the following Matlab routines can be downloaded from: <http://numanal.inf.elte.hu/~hegedus/matlab.html>

GSrank: QR decomposition with pivoting and rank finding

Pproj: Performs one projection step, called by GSrank

relarel: Corrected residual error for matrices

lsqsol: Least squares solution for $Ax=b$, where A is decomposed by GSrank.

4 Conclusions

A new theoretical background and modified versions of the "twice is enough" algorithm are given. Quite surprisingly, cancellation error considerations lead to a simpler proof. The success may suggest a wider use of cancellation phenomena in error investigations. Another surprise is the possibility of estimating the number of accurate digits after the first projection with the help of second projection data (ρ_{out} from (14)). The analysis gives an explanation of the extraordinary stability of ABS methods in some cases. The test problems shown justify the given statements and also reveal some unexpected numerical phenomena. Further, it is demonstrated that orthogonalizing twice assures a good quality of rank revealing QR-decompositions.

Acknowledgement

Professor J. Abaffy is thanked for his constant encouragement and help when writing this paper. Also, Szabina Fodor is highly appreciated for helpful discussions.

References

- [1] ABAFFY, J., AND SPEDICATO, E.: *ABS Projection Algorithms: Mathematical Techniques for Linear and Nonlinear Equations*, Ellis Horwood Limited, John Wiley and Sons, Chichester, England, (1989).
- [2] ABDELMALEK, N. N.: *Round off error analysis for Gram-Schmidt method and solution of linear least squares problems*, BIT 11 (1971) pp. 345-368
- [3] BARLOW, J. L.: *Reorthogonalization for the Golub-Kahan-Lanczos bidiagonal reduction*, Numerische Mathematik, 124 (2013) pp. 237-278
- [4] BJÖRCK, A.: *Solving linear least squares problems by Gram-Schmidt orthogonalization*, BIT 7 (1967) pp. 1-21
- [5] BJÖRCK, A. AND PAIGE, C.: *Loss and recapture of orthogonality in the modified Gram-Schmidt algorithm*, SIAM J. Matrix Anal. Appl. 13(1) (1992) pp. 176-190
- [6] CHAN, T. F.: *Rank revealing QR factorizations*, Lin. Alg. and its Applic. 88/89 (1987) pp. 67-82

- [7] FODOR, SZ.: Private communication.
- [8] Galántai, A. and Hegedüs, C. J.: *Jordan's principal angles in complex vector spaces*, Numerical Linear Algebra with Applications 13 (2006) pp. 589-598
- [9] GIRAUD, L., LANGOU J. AND ROZLOZNIK, M.: *On the round-off error analysis of the Gram-Schmidt algorithm with reorthogonalization*, CERFACS Technical Report No. TR/PA/02/33 (2002) pp. 1-11
- [10] GIRAUD, L., LANGOU J. AND ROZLOZNIK, M.: *The loss of orthogonality in the Gram-Schmidt orthogonalization process*, Computers and Mathematics with Applications, Vol. 51 (2005) pp. 1069-1075
- [11] GIRAUD, L., LANGOU J. AND ROZLOZNIK, M. AND VAN DEN ESHOF, J.: *Rounding error analysis of the classical Gram-Schmidt orthogonalization process*, Numer. Math. 101 (2005) pp. 87-100
- [12] GOLUB, G. AND VAN LOAN, C.: *Matrix Computations*, 3rd ed. John Hopkins Univ. Press, Baltimore, MD (1996)
- [13] GU, MIND AND EISENSTAT, STANLEY C.: *Efficient algorithms for computing a strong rank revealing QR factorization*, SIAM J. Sci. Comput. 17(4), (1996) pp. 848-869
- [14] DANIEL, J.W, GRAGG, W.B., KAUFMAN L. AND STEWART G.W.: *Re-orthogonalization and Stable Algorithms for Updating the Gram-Schmidt QR Factorization*, Mathematics of Computation 30(136) (1976) pp. 772-795
- [15] HEGEDÜS, C. J.: *Short proofs for the pseudoinverse in linear algebra*, Annales Univ. Sci. Budapest, 44 (2001) pp. 115-121
- [16] HIGHAM, N. J.: *Accuracy and Stability of Numerical Algorithms*, SIAM, Philadelphia, (1996)
- [17] HOFFMANN, W.: *Iterative Algorithms for Gram-Schmidt orthogonalization*, Computing Vol 41 (1989) pp. 335-348
- [18] PARLETT, B. N.: *The symmetric Eigenvalue Problem*, Englewood Cliffs, N. J. Prentice-Hall (1980)
- [19] RICE, J. R.: *Experiments on Gram-Schmidt orthogonalization*, Math. Comp. 20 (1966) pp. 325-328
- [20] RUTISHAUSER, H.: *Description of Algol 60*, Handbook for Automatic Computation, Vol 1a. Springer, Berlin, (1967)
- [21] SMOKTUNOWICZ, A. BARLOW, J. L. AND LANGOU, J.: *A note on the error analysis of classical Gram-Schmidt*, Numer. Math. 105(2) (2006) pp. 299-313
- [22] WILKINSON J. H.: *The Algebraic Eigenvalue Problem*, Oxford University Press (1965)
- [23] WILKINSON J. H.: *Rounding Errors in Algebraic Processes*, Prentice-Hall (1963)

User Preference Modeling by Global and Individual Weights for Personalized Recommendation

Ondrej Kassak, Michal Kompan, Maria Bielikova

Slovak University of Technology in Bratislava, Faculty of Informatics and Information Technologies, Ilkovičova 2, 842 16 Bratislava 4, Slovakia
{name.surname}@stuba.sk

Abstract: In this paper we propose a novel user model for personalized recommendation in domains, where items are described by multiple characteristics (e.g., metadata attributes) and users' preferences are expressed on the level of items by some kind of explicit feedback (e.g., rating) or derived from implicit user feedback (e.g., time spent on items). The proposed user model is composed of two parts. The first one represents user preferences by items descriptive metadata (e.g., genres, keywords, actors and directors in movie domain used as an example in this paper) expressed as preference vectors. The second part is represented by a vector describing user's preferences on previously rated items. Our main contribution is the addition of individual user preference measures to the vectors of both user model parts. User preferences expressed as the vector weights are calculated based on the global preference of large amount of users and also on individual variations in preferences of particular users to the average of the whole set of users. The weights reflect how much the different types of information are important to the user. We evaluated the proposed user model in movie domain through collaborative recommendation by comparing its performance to two reference user models using Movielens 10 M dataset.

Keywords: user model; weighted vector; user similarity; personalized recommendation; multimedia domain; movie recommendation

1 Introduction and Related Work

Information overload problem over the Web is often reduced by personalized recommendation. Methods of personalized recommendation are generally based on a user model that estimates the user's preferences or his/her interests relating to specific domain.

The issue of reducing information overload is currently researched for a number of domains, such as multimedia, texts, jobs, etc. From the user modeling point of view, there are several similar characteristics typical for these domains. At first,

these domain items are described by various metadata attributes. These attributes can be derived either from the items' content (e.g., keywords, header, subject) or can describe some items' characteristics (e.g., author, timestamp, genre, popularity, or sentiment [4]). In this way each item is characterized by a set of information. Moreover, the knowledge of user preferences is crucial to be able to model his interests. The feedback is captured in various forms from explicit ratings to implicit visits, time spent on items by the user, clicks or other signals of the user activity [9].

In this paper we propose a novel approach for user modeling for personalized recommendation in domains, where items are described by multiple characteristics and users' preferences are expressed on the level of items. We focus on the movie domain as a typical representative of above described domain characteristics, where is a huge users' activity over various web-based systems and services (expanding to more and more devices such as personal computers, TVs, mobile devices, etc.). The average U.S. citizen watches TV daily for 5.11 hours, which results in a total of 9 years during the person's lifetime. A schoolchild in the U.S. watches television an average of 1 200 hours per year, while they only spend 900 hours in the school classroom during the same time period (BLS American Time Use Survey, A.C. Nielsen Co., 2012). These statistics cover just watching TV, they do not indicate watching videos and movies on the internet, so we can expect these numbers to be actually even higher. Therefore, it is appropriate to help users in finding various options to choose items that interest them.

Humans in general have different interests and attribute different importance to things in comparison to other people [13]. For example, somebody chooses movies primarily by genre, another one by its director. At the same time, domain of movies is quite well-structured, i.e. the items like movies can be described by metadata that form several categories (e.g., genres, directors). Hu et al. in their work report that users tend to rate similarly the items which have multiple metadata elements in common [14]. This information in addition to the suitable metadata structure allows us to model user preferences by the mean of overlay user models and thus reflects user preferences in more detail. Our approach to user modeling follows the overlay user model concept. We proposed a mechanism which dynamically adjusts general weights according to individual user's behavior and the whole group of users' activities.

In the most general view Senot et al. [21] defined the user model, as a set of pairs [concept, value], while the value is from the interval $<0; 1>$, which represent a user's level of interest to the category of items (e.g., movies directed by Quentin Tarantino). The rate of interest is determined for example as the average amount of user's ratings of items in this category. Except the preference rate, Wang et al. propose to differ between long and short term preferences, which express the stability of user interest [23]. This could be realized for example by introducing also the concept of weights used to store the number of concept ratings.

The most widespread approach to user modeling (besides the Bayesian networks [7] and graph application [2, 22]) models user preferences based on individual users' preferences [5]. In movie domain such user models are often represented by a set of vectors. The vector models formed by genres, actors and keywords represent the basis for collaborative recommendation according to Yu et al. [26]. The authors in [12] use the genres as the only source of information. Mukherjee et al. defines user model as a set of genres, actors, actresses and director's vectors [19]. Wang et al. extends this concept to a set of multiple vectors, where each of them is used for different user's mood [24], which can be automatically recognized [17]. Vector user model formed by actors, directors, genres and keywords, where each vector element has calculated its own static weight, is used also by Debnah et al. [10]. Mutual similarities between the vector users models are generally computed using metrics such as Cosine similarity, Pearson correlation, Euclidean distance, etc. [24].

The main problem is that existing user models, do not sufficiently model what users seen as important and according to what aspects they decide primarily when selecting an item. This is possible to solve by understanding how much users are alike, not only by the selected items, but also according to the method of choice (decision making process). This way we improve the information value provided by the user model by the mean of more specificity levels, which is then used for recommendation. A similar idea is actually researched in the movie domain by Wen and Chen, who except for user ratings aim to find user similarity measure primarily by their personality traits, based on idea that users choose firstly by their personalities [25].

Our proposed approach estimates user's preferences not only from the low level preferences (e.g., specific genre or director) perspective, but as well, we model the higher level – found patterns based on how the user makes decisions (e.g., user attribute the importance to genres, or directors). In other words, not only the preference of specific genres (e.g., comedy) directors (e.g., Tarantino) is reflected in the proposed user model, but the way the user decides (e.g., he/she mainly decides by a director, fewer by genres) is considered primarily. This aspect, nowadays, is not considered in current user modeling approaches in the movie domain.

Our aim is to introduce in this paper a novel user model, which

- considers not only specific preference value for vector items (e.g., preference of comedy genre, Tarantino (director)), but a higher level of user preferences.

Identification of the way how the user decides when he/she chooses a movie seems to be very helpful knowledge for personalized recommendations. This knowledge (e.g., first he/she chooses the genre and after that some director known to him), offers us an advantage in comparison to existing methods of user modeling.

Our proposed concept can be used within several existing approaches as for example in shared interoperable user models [8] where it could be helpful to spread information about user decision preferences. At the same time, it can improve open editable user models [3], where it can suggest model vectors' preferences automatically. Similarly, it could ease the cold start [20] problem by setting the initial preferences.

2 User Model Components

To create a user model or to recommend items in a particular domain, it is necessary to be able to describe distinctive items or users' properties. In the movie domain it is common to get the user's feedback in the form of explicit ratings of items (e.g., movies). Working with multimedia content is, therefore, more challenging due to the lack of automatized approaches for content analysis in such a domain. On the other hand, thanks to this shortcoming, users are often involved by providing detailed information in order to produce metadata describing items characteristics. This rich metadata information such as title, genres, release date, languages, a list of directors, actors, keywords, etc. (typical for well-structured domains) is commonly used in order to model user preferences and to analyze distinctive features of the recommended items.

In order to model user preferences in various levels of abstraction we propose a novel weighted vector user model consisting of a set of vectors, which represent the user's preferences to particular characteristics of multimedia content based on available metadata (e.g., genres, keywords, directors and actors for movies) and the preferences to specific items themselves.

Un-weighted or only statically weighted vector models are currently widely used in various domains. Our contribution consists of the addition of individual weights to vectors forming the user model, while these are dynamically recalculated based on the user's behavior and behavior of all other users, as well. Thanks to our enhancement of individual weights to the model vectors we improved the representation and modeling of user's interests. In our proposed user model, the final weight for every vector is determined as a combination of initial global and individual weight parts.

Initial global weight represents the importance of the vector compared to the other user model's vectors (this helps us express user preferences in the mean of the preference of genres or directors, etc.). Its weight is the same for all users and is used as an initial setting for new users. Opposing this, *individual user weight* reflects variation in the interests of modeled user behavior compared to the average behavior of other users. Vector weights, model the users' decision making process (from the high level preference point of view).

Vectors and their weights in our user model are useful in the step of similar user search (often performed by recommender systems [16]) as it is beneficial to find similar users not only based on the low level user perspective (a user likes some actor), but from the high level perspective as well (user often decides based on actors).

Let D be an assembly of sets of descriptive metadata associated with items from modeled domain and P a set of user's item preferences. The user model UM is then defined as a couple:

$$UM = (D, P) \quad (1)$$

Each element of D represents a set of weighted vectors wv (descriptive metadata vectors as, e.g., genres, keywords, actors and directors for movie domain that aggregate metadata for each category and its values) from the set of all weighted vectors WV (all item metadata types).

$$D = \{wv_1, wv_2, \dots, wv_{n,n \in \mathbb{N}}\}, wv_{i,i \leq n} \in WV \quad (2)$$

P is a set of weighted user's item preferences (e.g., item ratings for movie domain), which is defined as the weighted vector wv from WV

$$P = \{wv_{m \in \mathbb{N}}\}, wv_m \in WV \quad (3)$$

The weighted vector wv is defined as a couple of a vector v and a final weight w of the vector v

$$wv_i = (v_i, w_i), i \in \mathbb{N} \quad (4)$$

where v is defined as set of k vector elements ve (actual metadata elements, e.g., comedy as actual genre, or Tarantino as actual actor):

$$v = \{ve_1, ve_2, \dots, ve_{k=|v|}\} \quad (5)$$

The Na is a set of all element names, Pm is an interval of all users' preference measures defined as $\langle \min \text{ preference}; \max \text{ preference} \rangle$ (e.g., set of possible rating values) and ew a number of elements preferences considered (e.g. number of ratings of the element). Then, the vector element ve is defined as a triple:

$$ve_i = (na_i, v_i, ew_i), i \leq |v|, na_i \in Na, v_i \in Pm, ew_i \in \mathbb{N} \quad (6)$$

The final vector weight w is computed as a sum of initial global weight igw (Equations 8, 9) and individual weight iw (Equation 10) precisely described in the Section 3.

$$w = igw + iw, igw \in \mathbb{R}, iw \in \mathbb{R} \quad (7)$$

In our example from movie domain we consider in the D user model part four weighted vectors wv_i – the genres, keywords, actors and directors. The P is represented by one weighted vector describing the user's preference measure for

items represented by item ratings. Weighted vectors for movie domain are described as follows:

Genres. Movie is usually described by several genres, as it is very rare to describe it by an only single genre. Because of the quality of today's metadata describing the item content, it is impossible to quantify the ratio of importance for several genres assigned to one movie, thus all genres obtain for the one movie an equal importance.

Keywords. In our model, keywords represent important terms, named entities (mainly persons, localities and events) or characteristic activities. Together they create a simple movie characteristic. Keywords are ordered based on their characterization relevancy (or by how many users used them to describe the movie). Thus, we are able to determine the keyword importance from its position in the ordered list assigned to every movie.

Actors. The cast is one of the most important factors, based on users making their decision and judging the movies. Just a presence of some famous actor or actress can be the reason that a user watches a movie, even if it is the only information about this movie he/she has.

Directors. The director is a person who influences the movie character and its atmosphere the most. Some types of users choose movies mostly by directors because they expect some patterns occurring in movies directed by the same director.

In addition to the descriptive attributes mentioned above, which do not capture the specific rated movie, but rather describe their properties (e.g., cast, genre), the user model includes the direct information about user's preferences, which we define for movie domain as user activity history expressed by movie ratings. This allows us to enhance the perception of user's rating history and reflect it in the proposed user model. An example of vectors v used in proposed user model for movie domain is shown in Table 1.

Table 1

Example of proposed user model consisting of four descriptive metadata vectors (genres, keywords, directors and actors) and user's items preference vector (rated movies). Vector elements are composed of set of triples element name, value, element weight.

Vector	Vector elements
Genres	[comedy; 4.0; 3], [action; 3.8; 5], [war; 1.5; 2], ...
Keywords	[journey; 3.4; 6], [hobbit; 4.5; 3], [shire; 3.1; 1], ...
Directors	[jackson; 4.1; 5], [tarantino; 4.2; 3], [lee; 1.2; 2], ...
Actors	[parsons; 4.1; 3], [streep; 5.0; 8], [cuoco; 4.1; 3], ...
Rated movies	[hulk; 3.0; 1], [avatar; 4.0; 1], [hours; 4.5; 1], ...

The proposed user model describes the user's preferences from several different perspectives (e.g., user preference of genres and actors). They are captured in the

form of vectors. The main contribution of the proposed user model is an addition of preference final vector weights w to the vectors. The weights are calculated individually for every modeled user. A detailed representation of the user preferences is used mainly to determine what criteria the user selects items by, or to identify the users who have the most similar interests as the actually modeled user. Advantage of the proposed vector model is its extensibility, whereas from the user model perspective vectors represent independent components.

3 Preference Modeling

The proposed user model itself is filled based on user's feedback provided for movie domain in the form of users' explicit items ratings (*movie x user rating*). In our user model we store preferences in the form of the low level characteristics, e.g., genres, actors (see Figure 1 left part). After the user rates an item, the item's metadata elements are adjusted in order to model low level user preferences (see Figure 1 middle and right part). This means that for every metadata element (i.e. for every movie genre, actor, etc.) is its value in the user model updated by actual rating value obtained from the user's feedback. For example, if the user rates a movie, which has defined as metadata 2 genres, 2 keywords, 1 director and 2 actors, there are in total 7 elements added or adjusted in the descriptive metadata part of his/her user model and the movie itself represented by some kind of identifier is added to the preference part of the user model.

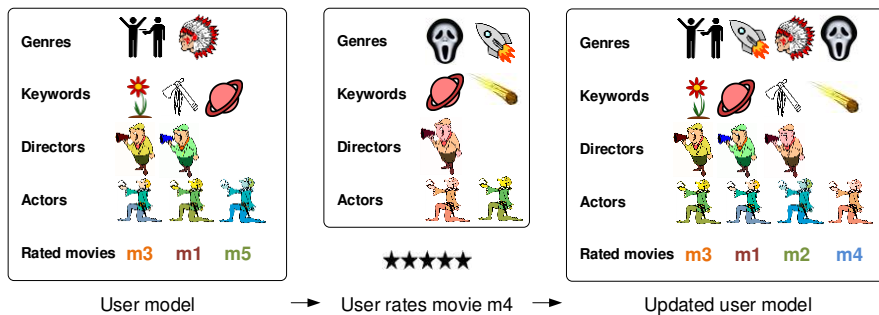


Figure 1

Principle for filling proposed user model by item ratings. The user (represented by the user model - left part, which was created based on three rated movies) gives a rating for a movie, which is described by some metadata (middle part). The rating is added to the user model for each metadata element (e.g., actors, directors, keywords for movie domain). In case the user model already contains some of the metadata elements (e.g., comedy for genres), the element *value* and *weight* are modified for these elements.

If the user rates a new item, vector elements adjustment involves the calculation of element *value* by adding new element *rating* (Equation 8). Consequently, the *weight* of that element is increased (positive rating scale is assumed).

$$value_{i,addition} = \frac{value_i * weight_i + rating_{i,new}}{weight_i + 1} \quad (8)$$

In a case, the user reevaluates the item he/she has rated in the past, the *values* of all its metadata elements are recalculated just as change of *rating* (Equation 9). The element *weight* does not change in this case because this action means the existing item *rating* is updated, but not added. This ensures the continuous updating of the user model and automatic concept drift handling, which is nowadays actively researched [15].

$$value_{i,change} = \frac{value_i * weight_i - rating_{i,old} + rating_{i,new}}{weight_i} \quad (9)$$

The level of user's interest is derived from the *values* of the individual vectors' elements. Our assumption is that the users are influenced by various *weights* not only in the mean of specific elements (one specific actor, genre, etc.) but also as the entire vectors. Someone chooses movies by actors who play in it or by people who directed it. But, for another user, this information is useless and he/she decides rather by the content (user is interested more in, e.g., keywords).

In other words, proposed approach models user's preferences are not only on the level of specific elements types (one specific genre, actor, etc.), but also the preferences of whole vectors are considered in the decision making process (Figure 2). For each vector the *final* individual preference *vector weight* (blue bar) is obtained by adjusting the *initial global weight* (grey bar, identical for each user) based on the users' decision making preferences – *individual weight* (green and orange bars with sign, different for individual users) – Equation 8. Preference weights can be used in the similarity search phase of recommendation approach.

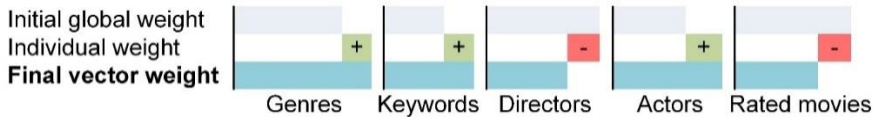


Figure 2

For each vector the final individual preference vector weight (blue bar) is obtained by adjusting the initial global weights (grey bar, identical for each user) by individual weights (green and red bars with sign, different for individual users).

The vector weights for some modeled user are determined as follows:

- 1) *For each new user assign initial global weights.* This step is the same for each user, weights are determined based on the average user decision making process (average of all users).
- 2) *Update the initial global weights by individual weights for each user.* Individual weights represent the user's interests' deviation to the average behavior of large amount of users. Thanks to this step, we are able to model user personal preferences on the higher level of abstraction.

Initial global weights. These kinds of weights serve as general rules and this step is obligate for all users equally. Initial global weights are used as starting weight values in the case of a new user (cold start). As user initiates actions (rates items), these weights are changed by the individual weighting mechanism, described below.

Individual weights. Individual preferences are represented as user's preferences deviations in comparison to the average user (computed as the average of preference stereotypes of all users).

Average preferences represent the average interest of all available users in the system. With this kind of interest, we search for each vector in the user model. Individual user preferences of modeled user are computed for each vector as the sum of the deviations to the average preferences divided by the number of vector items (Equation 10). Thus, we get the absolute value of the difference between element frequencies of the modeled user vector and the element frequencies of the average user, called the average deviation (introduced by Ferman et al. [12]). In their work, however, was the sum of deviations calculated as elements division. In our user model we use subtraction because it captures (based on comparison we performed) the real observed deviations more precisely.

$$individual\ weight = \frac{\sum_{i=0}^N |\overline{item\ weight}_i - item\ weight_i|}{N} \quad (10)$$

where N is the number of elements of the vector. *Weight* of each element reflects the number of rated items, which metadata contains this element. For example, if we calculate the *weight* of a comedy element belonging to the genres vector, we consider rated movies that contain genre comedy. After computation of the all vector preferences in both model parts, (all metadata vectors and the items vector), the measured values are normalized so the sum of their values will be equal to 1 as:

- 1) According to the previously described procedure (Equation 10) calculate individual preference of all vectors in a user model.
- 2) Calculate the inverse sum of absolute values of preferences from step 1.
- 3) For each vector multiply results of step 1 and step 2.

Normalization process gives for each preferences vector a value from the interval $<0; 1>$. Preferences represent the personal user model vector importance for modeled user.

4 Experiment Evaluation

We evaluated the proposed user model indirectly by the personalized recommendation based on several reference user models, which is commonly used in domain on user modeling evaluation [18].

Our hypothesis is that the proposed user model including vectors of elements that describe rated items and considering personal preferences of these vectors improves precision of collaborative recommendation in comparison with a user model without mentioned features.

To verify our hypothesis we compared precision of collaborative recommendation based on proposed user model and reference user model generally used in the multimedia domain [1, 11].

4.1 Dataset and Methodology

In order to evaluate proposed weighted vector user model we used Movielens 10 M dataset (<http://grouplens.org/datasets/movielens/>). The dataset contains ratings from nearly 70 k users (min. 20 ratings per user) on over 10.5 k items. Each rating is characterized by unique identifier, a string containing the name in English followed by release year, set of movies genres and the rating value.

Since the dataset contains only genres of movies as the metadata information, we needed to expand the metadata information. We used the data obtained from the Internet Movie Database (IMDb) including the original item title, the official translation of title for the English language, list of genres, keywords, actors, directors along with information about them, the item content, release date, duration, etc. As an extension of these IMDb data, we modified the set of keywords because of their low quality. We used a text analysis based on the TF-IDF algorithm and replaced some keywords with synonyms and adjusted their weights by re-order.

Process of items mapping was realized by the means of matching pairs of items from IMDb and Movielens (based on the release date and the title). As the result, we obtained over 8.5 million ratings for which we were able to clearly match the rated item and its description from IMDb. In this manner we obtained ratings from 3 k users. Together, processed users give over 331 k ratings which resulted in over 4.5 million of mutual similarities between the pairs of users in each recommendation method used for experiments.

For each user we randomly assigned his/her ratings to the 80% training and 20% testing set. Using the training set, we created user models (for our proposed vector model and reference models respectively). Based on these models, we have calculated the mutual similarity between users and then produced the top-N collaborative recommendations.

4.2 Results

For evaluation of proposed user model we compared it to the reference user model generally used in the multimedia domain [1, 11]. The comparison was realized as collaborative user top-N recommendation. Generated recommendations were based on the reference user model used cosine similarity (as the proposed model did) and respectively the Pearson correlation. For quantitative evaluation we used the standard widely-used precision metric, which represents the proportion of items selected by the user from the recommended set and the total number of recommended items available (prec@1, 3, 5, 10, 15).

Results clearly show (Table 2) that the top-N collaborative recommendation based on the proposed user model achieves statistically significant better results than compared recommendation based on reference user model in the movie domain using cosine similarity and the Person correlation. When recommending one item (prec@1) our method achieves the precision of 61.61%, what means an improvement of 17.20% comparing to the cosine similarity and 23.04% comparing to the Pearson correlation. When recommending the list of 15 items (prec@15) our method achieved precision of 42.94% and improvements of 7.98% and 11.26%.

Table 2

Results of the experiment comparing the precision of collaborative recommendation based on various approaches of the users similarity computation step (CS – cosine similarity, PC – Pearson correlation)

	Weighted vector UM	Reference UM using CS [1, 11]	Reference UM using PC [1, 11]
prec@1	61.61	44.41	38.57
prec@3	51.53	36.74	34.48
prec@5	48.38	36.10	33.51
prec@10	44.35	35.30	32.45
prec@15	42.94	34.96	31.68

The paired T-test was performed in order to investigate the statistical significance. Obtained results are by the general criteria considered as highly statistically significant ($p = 0.0047$, $\alpha = 0.05$ and $t = 7.6401$ for cosine similarity and $p = 0.0058$, $\alpha = 0.05$, $t = 7.0895$ for the Pearson correlation). From these results it is clear that the top-N recommendation using the proposed user model achieves significantly higher precision in comparison to the same recommendation based on reference models.

As we can see our proposed user model achieves the best results when recommending a lower number of items. In fact, this represents in the domain of movie recommendation the ideal situation. In this domain, it takes relatively long time to experience some item and users usually watch only one movie per session. It is, therefore, unnecessary to recommend him/her too many items, but on the other hand, the precision of first few recommended items is crucial from the users' satisfaction point of view.

Conclusions

The main contribution presented in this paper lays in the proposal of a personalized weighting approach for vectors describing users' preferences, which allows us to model user's preferences from various perspectives. Vector weights reflect the high level importance of the information contained in the vector (e.g., genres, keywords, directors) for the modeled user. The proposed user model consists of two parts – *descriptive metadata part* consisting for movie domain of four vectors (genres, keywords, directors and actors) and the *items preference part* described by one vector (rated items identifiers for movie domain). Vectors are composed of elements that capture user's interests based both on metadata and users' rating activity.

The user model principle is generally reusable to any domain, in which items can be described by metadata. An example is the domain of news [6] where, similarly to movie domain, items are described by a set of metadata attributes and there is a need to consider the vector importance. In general, for the user model to be reused it is necessary only to extract the most descriptive (or distinctive) metadata from the target domain and replace the currently used ones. The vector weight expresses how much is the particular type of information described by the vector (e.g., genre, director) important for the user when he/she is choosing some items. In other words, we model general preferences of user decisions, e.g., whether the user generally decides according to a director or rather by genres. For new users (we do not have enough user rating history), vectors' weights are calculated based on the generally applicable rules – the global vector weights. Next, as the user rates more items, they are adjusted by individual weights. Individual weights express how much the user differs from the average behavior of (possibly a large number of) other users.

The proposed user model can be extended by adding further vectors reflecting specific domain characteristics. This extension is from the computational perspective of proposed approach is not critical because it increases linearly. The process of updating elements to the user model is in fact inexpensive operation consisting of updating values and weights only of elements describing the item. An update operation was, in Section 3, illustrated on the explicit user rating, which is the most common format of user feedback used in the movie domain. Any other user feedback format can be used, which enables us to describe user interests on the level of items (the numeric interval expressing user's interest is required). The only requirement is to have data (measure) on user interest related to the items.

The benefits of the proposed user model are mostly in achieving a higher precision in recommendations based on the proposed user model, compared with the reference user models. The advantage of our user model is also the coverage of the user's interests from multiple perspectives. Moreover, by considering the global and individual weights, the proposed approach is able to help the recommendation algorithms to overcome some problems, such as a cold start. For the new user we

can apply general rules for the decision making preferences and start recommend suitable items as soon as possible.

Acknowledgement

This work was partially supported by the Scientific Grant Agency of the Slovak Republic, Grant No. 1/0646/15, the Cultural and Educational Grant Agency of the Slovak Republic, Grant No. KEGA 009STU-4/2014, and it is the partial result of the Research and Development Operational Programme for the project International centre of excellence for research of intelligent and secure information-communication technologies and systems, ITMS 26240120039, co-funded by the European Regional Development Fund.

References

- [1] G. Adomavicius, A. Tuzhilin: Toward the Next Generation of Recommender Systems: A Survey of the State-of-the-Art and Possible Extensions, *IEEE Transactions on Knowledge and Data Engineering* 17(6), (2005) pp. 734-749
- [2] C. C. Aggarwal, J. L. Wolf, K. L. Wu, P. S. Yu: Horting Hatches an Egg: A New Graph- Theoretic Approach to Collaborative Filtering, *Proceedings of the 5th ACM SIGKDD international conference on Knowledge discovery and data mining (KDD '99)* (1999) pp. 201-212, ACM, New York, NY, USA
- [3] J. Ahn, P. Brusilovsky, S. Han: Personalized Search: Reconsidering the Value of Open User Models, *Proceedings of the 20th International Conference on Intelligent User Interfaces (IUI '15)* (2015) pp. 202-212, ACM, New York, NY, USA
- [4] O. Appel, F. Chiclana, J. Carter: Main Concepts, State of the Art and Future Research Questions in Sentiment Analysis, *Acta Polytechnica Hungarica*, 12(3) (2015)
- [5] M. Barla, M. Tvarožek, M. Bielíková: Rule-based User Characteristics Acquisition from Logs with Semantics for Personalized Web-based Systems. In *Computing and Informatics*, 28(4) (2009)
- [6] M. Bielíková, M. Kompan, D. Zeleník: Dušan, Effective Hierarchical Vector-Based News Representation for Personalized Recommendation. *Computer Science and Information Systems* 9(1) (2012) pp. 303-322
- [7] J. S. Breese, D. Heckerman, C. Kadie: Empirical Analysis of Predictive Algorithms for Collaborative Filtering, *Proceedings of the 14th conference on Uncertainty in artificial intelligence (UAI'98)* (1998) pp. 43-52, Morgan Kaufmann Publishers Inc., San Francisco, CA, USA
- [8] M. Chevalier, C. Julien, C. Soulé-Dupuy: User Models for Adaptive Information Retrieval on the Web: Towards an Interoperable and Semantic

- Model. International Journal Adaptive, Resilient and Autonomic Systems, 3, 3 (July 2012) pp. 1-19, IGI Publishing Hershey, PA, USA
- [9] D. Chuda, P. Kratky, J. Tvarozek: Mouse Clicks Can Recognize Web Page Visitors!, Proceedings of the 24th International Conference on World Wide Web (WWW '15 Companion) (2015) pp. 21-22
- [10] S. Debnath, N. Ganguly, P. Mitra: Feature Weighting in Content-based Recommendation System using Social Network Analysis. Proceedings of the 17th international conference on World Wide Web (WWW '08) (2008) pp. 1041-1042, ACM, New York, NY, USA
- [11] C. Desrosiers, G. Karypis: A Comprehensive Survey of Neighborhood-based Recommendation Methods. Recommender Systems Handbook, Springer (2011) pp. 107-144
- [12] A. M. Ferman, P. Van Beek, J. H. Errico, M. I. Sezan: Multimedia Content Recommendation Engine with Automatic Inference of User Preferences. Proceedings of the IEEE International Conference on Image Processing (2003) pp. 49-52, IEEE
- [13] B. Ferwerda, M. Schedl, M. Tkalcic: Personality & Emotional States: Understanding Users' Music Listening Needs, User Modeling, Adaptation, and Personalization (2015) Springer International Publishing
- [14] L. Hu, A. Sun, Y. Liu: Your Neighbors Affect your Ratings: on Geographical Neighborhood Influence to Rating Prediction. Proceedings of the 37th International ACM SIGIR Conference on Research & Development in Information Retrieval (SIGIR'14) (2014) pp. 345-354
- [15] J. Kiseleva, E. Crestan, R. Brigo, R. Dittel: Modelling and Detecting Changes in User Satisfaction. Proceedings of the 23rd ACM International Conference on Information and Knowledge Management (CIKM'14) (2014) pp. 1449-1458, ACM, New York, NY, USA
- [16] M. Kompan, M. Bieliková: Personalized Recommendation for Individual Users Based on the Group Recommendation Principles. Studies in Informatics and Control 22(3) pp. 331-342
- [17] P. Korenek, M. Šimko: Sentiment Analysis on Microblog Utilizing Appraisal Theory. In World Wide Web. 17(4) (2014) pp. 847-867, Springer, USA
- [18] J. Kim, L. Daesung, C. Kyung-Yong: Item Recommendation Based on Context-Aware Model for Personalized u-Healthcare Service. In Multimedia Tools and Applications 71(2) (2014) pp. 855-872
- [19] R. Mukherjee, N. Sajja, S. Sen: A Movie Recommendation System - An Application of Voting Theory in User Modeling. User Modeling and User-Adapted Interaction 13(1-2) (2003) pp. 5-33

- [20] M. H. Nadimi-Shahraki B. Mozhode: Cold-start Problem in Collaborative Recommender Systems: Efficient Methods Based on Ask-to-rate Technique. CIT. Journal of Computing and Information Technology 22.2 (2014) pp. 105-113
- [21] C. Senot, D. Kostadinov, M. Bouzid, J. Picault, A. Aghasaryan, C. Bernier: Analysis of Strategies for Building Group Profiles. Proceedings of the 18th international conference on User Modeling, Adaptation, and Personalization (UMAP'10) (2010) pp. 40-51, Springer-Verlag, Berlin, Heidelberg
- [22] A. Tiroshi, S. Berkovsky, M. Kaafer, D. Vallet, T. Kuflik: Graph-based Recommendations: Make the Most Out of Social Data, In Proceedings of the 22nd international conference on User Modeling, Adaptation, and Personalization (UMAP'14) (2014) pp. 447-458, Springer International Publishing
- [23] H. Wang, Y. Liu, P. Yin: Study on User Preferences Modelling Based on Web Mining. International Journal of Information Technology and Management 11, 4 (October 2012) pp. 307-322, Inderscience Publishers
- [24] L. Wang, X. Meng, Y. Zhang, Y. Shi: New Approaches to Mood-based Hybrid Collaborative Filtering. Proceedings of the Workshop on Context-Aware Movie Recommendation (CAMRa '10) (2010) pp. 28-33, ACM, New York, NY, USA
- [25] W. Wen, L. Chen: Implicit Acquisition of User Personality for Augmenting Movie Recommendations. Proceedings of the 23rd international conference on User Modeling, Adaptation, and Personalization (UMAP'15) (2015) pp. 302-314, Springer International Publishing
- [26] Z. Yu, X. Zhou, Y. Hao, J. Gu: TV Program Recommendation for Multiple Viewers Based on user Profile Merging. User Modeling and User-adapted Interaction 16(1) (2006) pp. 63-82

An Approach to Robust Biometric Key Generation System Design

**Nemanja Maček¹, Borislav Đorđević², Jelena Gavrilović³,
Komlen Lalović⁴**

¹ SECIT Security Consulting, 21 Aksentija Maksimovića Street, 26000 Pančevo, Serbia; e-mail: nmacek@secitsecurity.com

² Mihailo Pupin Institute, University of Belgrade, 15 Volgina Street, 11060 Belgrade, Serbia; e-mail: borislav.djordjevic@pupin.rs

^{3,4} Faculty of Informatics and Computing, Singidunum University, 32 Danijelova Street, 11000 Belgrade, Serbia,
e-mails: jgavrilovic@singidunum.ac.rs, komlen.lalovic.13@singimail.rs

Abstract: This paper presents a novel approach to the design of robust multimodal biometric cryptosystems. The design objectives behind the system are robustness, privacy of user's biometric templates and stable cryptographic key generation. The framework presented in this paper employs two modalities and a look-up table. The hashes of cryptographic keys generated from a biometric template during the enrollment phase are stored in the look-up table with cancelable templates generated from the sample belonging to different modality of the same subject. During the operation phase, the system releases the key, only if the hash of the key generated from the provided biometric sample is found in the look-up table, and the similarity score between corresponding cancelable templates is less than a predefined threshold. The implementation of the proposed framework with iris and fingerprint biometrics is evaluated with the CASIA biometric template database.

Keywords: biometry; multimodal; cryptography; key generation; robustness

1 Introduction

“Biometrics is the science of establishing the identity of an individual based on physical, chemical or behavioral attributes of the person” [1]. Due to the distinctive nature of biometric traits [2] and the non-repudiation it offers [3], biometry is frequently used to enhance the overall security of the system in which it is implemented: the authentication system or the biometric cryptosystem.

Biometric authentication is the process of validating the uniqueness of individuals according to their physiological or behavioral qualities [4]. Physiological qualities,

such as a fingerprint, an iris or a face, refer to something that an individual is. Behavioral qualities, such as speech, signature and keystroke dynamics refer to something that an individual can do. According to Biggio [5], the generic modular biometric authentication system operates as follows. A user who wants to access some resources provides his identity. The sensor acquires the biometric sample of the user. Features are extracted from the sample and a similarity score is calculated between the provided biometric sample and the one stored in the biometric template database corresponding to the provided user identity. The similarity score is compared with the threshold and the user is identified as genuine or an impostor. According to this decision, the access to resources is granted or denied.

There are several advantages of biometric authentication over traditional authentication methods, such as difficulties in stealing, sharing and reproduction of biometric samples, tolerance to brute force attacks, and non-repudiation (an authenticated user cannot deny his activities) [6].

There are two types of biometric systems: a unimodal, which employs a single biometric sample acquired from the user, and a multimodal, which employs two or more modalities, e.g. an iris and a fingerprint. Multimodal systems prevail over some drawbacks of unimodal systems, such as large false rejection rates (FRR) and unacceptable false acceptance rates (FAR): additional information provided to the classifier increases the recognition accuracy and decreases error rates, while the identity proof is strengthened as data is acquired from different sources [7]. When compared to unimodal, multimodal systems are less prone to spoof attacks [8] and carefully crafted attacks targeted towards modular biometric authentication systems (replaying old data, feature extractor overriding, stored template modification, communication channel interception and providing synthetic vectors to the matching module) [9, 10].

The basis of multimodal biometric authentication systems is the information fusion. The decision level fusion [11] is the initial approach to information fusion in multimodal biometric authentication systems. This approach is based on majority vote scheme that is used to combine classification results from different modalities and make the final decision [12]. At the matching score level [13], the system calculates similarity scores between the sample and the corresponding template for each modality and combines them to verify the identity of an individual. At the feature level, feature vectors extracted from different modalities are integrated into a new vector that represents the identity of the individual [14].

Biometric cryptosystems, such as, key generation and key binding systems, combine a high level of security that is provided by cryptography and non-repudiation provided by biometry. Key generation systems are systems that produce a stable cryptographic key that is extracted from biometric data [15, 16]. Key binding systems are systems that bind a randomly generated cryptographic key to the biometric template [17, 18]; the bound key is released to the application

upon a valid presentation of the appropriate biometric template. Stored biometric samples pose a risk to users' privacy. If stored in an insecure manner, an adversary may carry out an identity theft attack on the cryptosystem. Defense strategies include the protection of stored templates with cancelable biometrics (intentional distortion of biometric features with non-invertible transforms) and the usage of multimodal biometrics.

Again, the main thrust of this paper is a novel approach to robust biometric cryptosystem design. The proposed system is the hybrid multimodal system that employs one biometric sample to generate a stable cryptographic key and another sample belonging to a different modality to authenticate the user. The design objectives are a stable bitstream, improved robustness, biometric template privacy and the reduction of false acceptance rates. According to the design objectives, the system employs a look-up table that stores the hashes of keys generated during the enrollment phase and cancelable biometric templates used for identity verification. This increases the overall security of the system – an adversary cannot obtain the biometric key or the authentication template as the data stored in the look-up table is processed with non-invertible transformations. The implementation of the proposed framework that employs an iris as the key generation biometrics and a fingerprint as the user authentication biometrics has been experimentally evaluated with the samples from the CASIA biometric template database.

2 Related Work

Chang et al. [16] proposed a framework for stable cryptographic key generation from unimodal biometric traits that are unstable in nature. The main contribution of their research is the approach to generating distinguishable biometric features, resulting in a stable cryptographic key. Although the performance of the proposed framework is evaluated with the face database containing facial expressions and head motion variations, the authors have stated that the framework is applicable to other biometric modalities as well.

Many studies that examine the usage of fingerprints in key generation systems and cancelable biometrics are reported in the literature. Tuyls et al. [19] have extracted consistent and reliable information bits from fingerprint samples using a set of four complex Gabor filters and BCH (Bose-Chaudhuri-Hocquenghem) error correction codes. However, FAR ranging from 2.5% to 3.2% is an unacceptable result for generated 45 bit and 89 bit keys. According to Solanki and Patel [20] it is possible to generate a 128 bit cryptographic key from fingerprint biometrics using Gabor filtering, but no FRR or FAR rates are reported. Ratha et al. [21] presented several methods to generate multiple cancelable identifiers from fingerprint images. Authors compared the performance of Cartesian, polar, and surface folding transformations of the minutiae positions and provided a proof that

the transforms are non-invertible. The fingerprint authentication system presented by Ang et al. [22] employs a key-dependent transformation of biometric data. Key-dependent transforms allow different templates to be stored for different applications, reducing the chance to link biometric template to an individual.

Hao et al. [23] developed a two-layer error correction technique that merges Hadamard and Reed-Solomon codes, thus providing a secure way to incorporate the iris biometrics into cryptographic applications. According to authors, an error-free 140 bit key can be reproduced from biometric samples with acceptable 0.47% FRR and 0% FAR rates, while a 192 bit key can be reproduced with 3.65% FRR and 0% FAR rates. Bae et al. [24] presented a novel feature extraction algorithm, based on independent component analysis for iris recognition. According to the authors, the proposed method has a similar Equal Error Rate (EER) to conventional methods based on Gabor wavelets, while the iris code size and feature extraction time have been significantly reduced.

Wu et al. [25] have developed a novel face biometric cryptosystem that uses a 128-dimensional principal component analysis vector and error correction codes (ECC) generated by Reed-Solomon algorithm. During the decryption phase, a biometric key is generated using the look-up table created at the encryption stage and the final key is obtained using both the biometric key and ECC. Sashank Singhvi et al. [26] developed a technique that exploits an entropy dependent feature extraction process coupled with Reed-Solomon error correction, resolving an issue resulting from the different acquisition of similar biometric samples. The authors have evaluated this technique with 3D face data and have concluded that the technique reliably produces 128 bit AES keys. The non-conventional methods of face feature extraction are presented by Ban et al. in [27]: HLO (hidden layer output) images are generated by the feature extraction of the multilayer perceptron in auto-association mode, while INDEX images are formed by a self-organized map used for image vector quantization.

Although the majority of research in multimodal biometrics is related to authentication, there are several researches related to cryptographic key generation reported in the literature, e.g. the feature fusion of an iris and minutiae [6], combining biometric features of an iris and a retina [28], or an iris and a face [29].

3 Proposed Framework

The main idea behind our approach is to combine a unimodal key generation system and a unimodal biometric authentication system into a robust multimodal biometric cryptosystem that will generate a stable bitstream with a 0% false acceptance rate. The framework of the proposed system that employs a strict decision level fusion approach is presented in Figure 1 (enrollment phase) and

Figure 2 (operating phase). During the enrollment phase, a user provides two biometric samples to the system. One sample is used to generate the key and another (belonging to different modality) is used to authenticate the user. In the enrollment phase the following steps are performed:

- 1) Biometric data used to generate the key is acquired by the sensor.
- 2) Data is preprocessed, features are extracted, and a cryptographic key is generated from the biometric template.
- 3) The hash of the cryptographic key is calculated.
- 4) Biometric data used for the authentication is acquired by another sensor.
- 5) Data is preprocessed and a cancelable biometric template is generated with non-invertible transforms.
- 6) The hash of the generated key and a cancelable biometric template are stored in the look-up table.

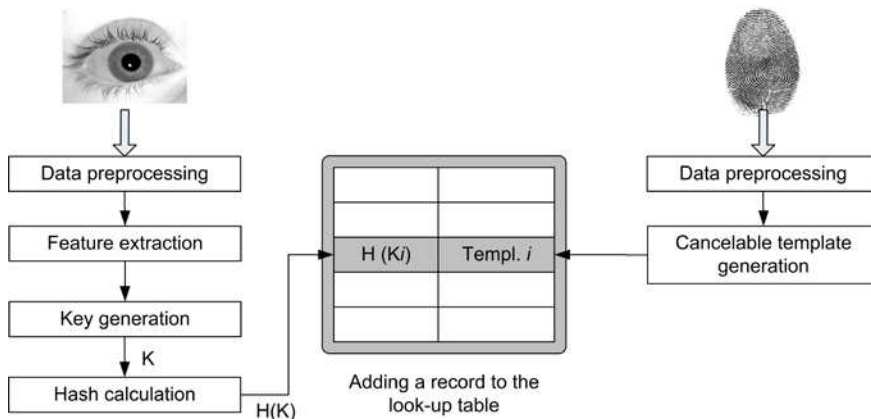


Figure 1

Robust multimodal biometric key generation framework (enrollment phase)

At the operating phase, a user provides two biometric samples to the system. The system performs the same 1-5 operations, as in the enrolment phase. Once the hash of the generated key and the cancelable biometric template are generated from the provided biometric samples, the system seeks the corresponding hash in the look-up table. If no hash matching the calculated one is found in the table, the system releases no key to the application and the user must provide his biometric sample again. If the matching hash is found, the system calculates the similarity score between the generated cancelable biometric template and the one stored in the look-up table corresponding to the hash. According to the similarity score, the system decides whether to release the key to the application or not.

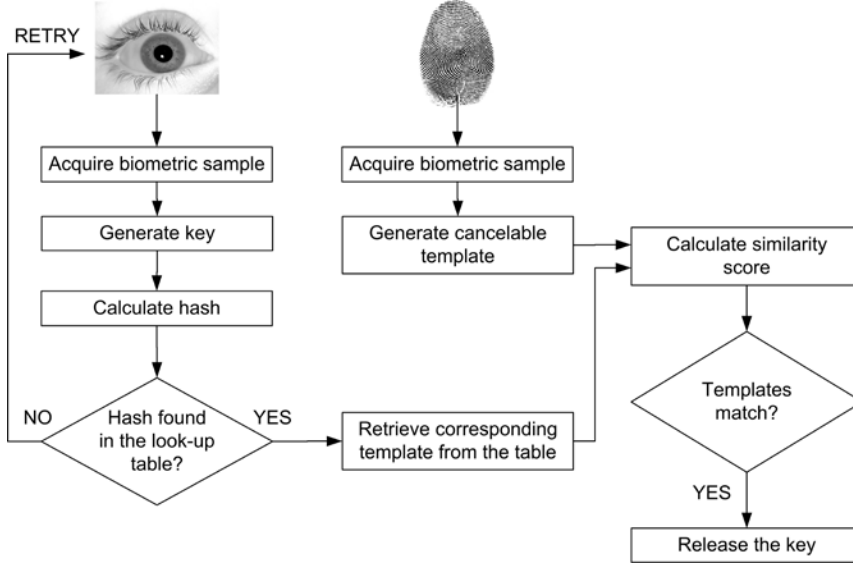


Figure 2

The operating phase of the proposed system

To sum up, the key is released to the application only if:

- The hash calculated from the key produced from the provided biometric sample is found in the look-up table, and
- The similarity score calculated between the generated cancelable biometric template and the one stored in the look-up table is less than the predefined threshold.

3.1 Security Evaluation of the Proposed Framework

Before we present one possible implementation of the framework, some general observations regarding the stability of a generated bitstream and overall system security are discussed.

The system stores hashes of generated keys for each user of the system in the look-up table. A slight modification in results obtained from a key generation process during the operation phase will result in a different calculated hash. As the key is released to the application only if the corresponding hash is found, it can be concluded that the system releases identical keys from the same biometric sample every time the user provides it. According to that, we conclude that the system produces the stable key.

The security of the system and the privacy of biometric templates are provided by one-way hash functions and non-invertible transforms. If an adversary obtains access to the look-up table, it is still impossible for them to regenerate the key or biometric templates that are produced during the enrollment phase. This results in a robust system with a 0% false acceptance rate (excluding brute force attacks). According to the attack taxonomy of Barreno et al. [30], the system cannot be compromised by targeted attacks: even if an adversary obtains access to the look-up table, he cannot select the user ID whose integrity he wants to compromise, as user identities are not stored in the table. The only drawback of the system is possible indiscriminate availability violations, as an adversary might randomly change stored hashes and cancelable templates, which could result in DoS to genuine users. However, all authentication systems are vulnerable during the enrollment phase and the aforementioned conclusions apply only to systems that are not compromised during that phase.

4 Implementation of the Proposed Framework: Iris and Fingerprint

This section presents the implementation of the proposed framework. Iris biometrics is used to generate the cryptographic key and a fingerprint to authenticate the user. Conventional methods are used to generate the key from an iris and extract minutiae points from a fingerprint. A cancelable template is generated by simple and effective non-invertible cell shuffling proposed by authors, which is a key-less modification of Ratha et al. Cartesian transform [21].

4.1 Generating Cryptographic Key from Iris Biometrics

More than 250 distinguishing characteristics of an iris (degrees of freedom) can be used in biometrics, resulting in six times more identifiers than the fingerprint [31]. Before the key is generated from extracted features, the acquired iris image must be preprocessed. The outer radius of iris patterns and pupils are first localized with Hough transform that involves a canny edge detector to generate an edge map. A poorly localized iris will result in unsuccessful segmentation and poor reproducibility of the key. This step is crucial in the enrollment phase, as extreme FRR may result in DoS to legitimate users. A Hough transform identifies the positions of circles and ellipses [32]: it locates contours in an n -dimensional space by examining whether they lie on curves of a specified shape. Hough transform for outer iris and pupil boundaries and a set of n recovered edge points (x_i, y_i) is defined by:

$$H(x_c, y_c, r) = \sum_{i=1}^n h(x_i, y_i, x_c, y_c, r), \quad (1)$$

$$h(x_i, y_i, x_c, y_c, r) = \begin{cases} 1, & (x_i - x_c)^2 + (y_i - y_c)^2 - r^2 = 0 \\ 0, & (x_i - x_c)^2 + (y_i - y_c)^2 - r^2 \neq 0 \end{cases} \quad (2)$$

The circle (x_c, y_c, r) through each edge point (x_i, y_i) is defined as:

$$(x_i - x_c)^2 + (y_i - y_c)^2 = r^2. \quad (3)$$

The triplet that maximizes $H(x_c, y_c, r)$ is common to the greatest number of edge points and is a reasonable choice to represent the contour of interest [33]. Similar technique that uses parameterized parabolic arcs is used to detect upper and lower eyelids. Once an iris image is localized, regions of interests are defined and it is transformed into fixed-size rectangular image. The normalization process employs Daugman's homogeneous rubber sheet model that remaps the iris image $I(x, y)$ from Cartesian (x, y) to polar coordinates (r, θ) [34]:

$$I(x(r, \theta), y(r, \theta)) \rightarrow I(r, \theta). \quad (4)$$

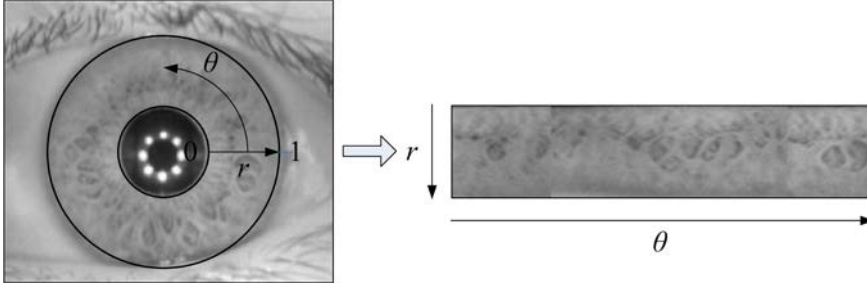


Figure 3

Daugman's rubber sheet model: localized iris (left) and normalized iris (right)

Parameter r is on the interval $[0, 1]$ and θ is the angle $[0, 2\pi]$. If iris and pupil boundary points along θ are denoted as (x_i, y_i) and (x_p, y_p) , respectively, the transformation is performed according to:

$$x(r, \theta) = (1 - r)x_p(\theta) + x_i(\theta), \quad (5)$$

$$y(r, \theta) = (1 - r)y_p(\theta) + y_i(\theta). \quad (6)$$

The rubber sheet model does not compensate rotational inconsistencies, but it takes into account pupil dilation size inconsistencies in order to produce a normalized representation with constant dimensions [31] set by angular resolution (the number of radial lines generated around the iris region) and radial resolution (the number of data points in the radial direction).

Although various extraction methods are reported in the literature, discriminant features are extracted from a normalized iris using conventional method based on Gabor filtering. This method is validated as suitable feature extraction method in various researches presented by other authors. A normalized image is broken into a number of 1-D signals that are convolved with 1-D Gabor wavelets. The frequency response of 1-D log-Gabor filter, introduced by Field [35] is given by:

$$G(f) = e^{-\left(\log \frac{f}{f_0}\right)^2 / 2 \left(\log \frac{\sigma}{f_0}\right)^2}, \quad (7)$$

where f_0 denotes center frequency, and σ denotes the bandwidth of the filter. Phase quantization is applied to four levels on filtering outputs (each filter produces two bits of data for each phasor) and the quantized phase data is used to encode an iris pattern into a bit-wise biometric template. An error correction code is generated using the Reed-Solomon algorithm and the template is digested into a key. The number of bits in the biometric template depends on angular and radial resolution and the number of used filters, while the template entropy depends on the number of used filters, their center frequencies and the parameters of the modulating Gaussian.

4.2 Minutiae Points Extraction

Minutiae points are extracted from the fingerprint biometrics prior to cancelable template generation. This procedure consists of several steps: preprocessing, segmentation, orientation field estimation, image enhancement and minutiae extraction.

The first operation applied to the acquired sample is histogram equalization, which increases the local contrast of the image. The Wiener filter removes blur and additive noise from the picture without altering ridge structures of the fingerprint biometric sample. Let $H(u, v)$ denote the Fourier transform of the point spread-function of the degradation process $h(x, y)$ and $H^*(u, v)$ the complex conjugate of degradation function. The Wiener filter [36] in frequency domain is given by:

$$W(u, v) = \frac{H^*(u, v)}{|H(u, v)|^2 + P_n(u, v)/P_s(u, v)}, \quad (8)$$

where $P_n(u, v)$ denotes the power spectrum of the noise and $P_s(u, v)$ is the power spectrum of the under-graded image $f(x, y)$. If blur is negligible and only additive noise needs to be removed, the filter takes the form:

$$W(u, v) = \frac{P_s(u, v)}{P_s(u, v) + \sigma_n^2}, \quad (9)$$

where σ_n^2 is the noise variance. The output of the Wiener filter is divided into equal-sized non-overlapping blocks. Let N denote the size of the block and $\mu(I)$ the mean pixel value of the block. The block I is considered to be a foreground block if its variance is greater than the threshold τ_s :

$$\sigma^2(I) = \frac{1}{N^2} \sum_{i=1}^N \sum_{j=1}^N (I(i, j) - \mu(I))^2 > \tau_s \quad (10)$$

This process is referred to as segmentation and is used to separate the regions of interest from the rest of the image. The next step in the extraction process is the estimation of orientation field (the local orientation of ridge valley structures), which is also a block-wise operation. The approach to orientation field estimation used in this research is gradient based. Gradient vectors indicate the highest deviation of gray intensity that is normal to the edge of ridge lines [37]. Let g_x and g_y denote gradient vectors of the block centered at pixel (i, j) in horizontal and vertical directions, respectively. The orientation θ of each block is given by:

$$\theta = \frac{1}{2} \tan^{-1} \left(\frac{\sum_{i=1}^N \sum_{j=1}^N 2g_x(i, j)g_y(i, j)}{\sum_{i=1}^N \sum_{j=1}^N (g_x^2(i, j) - g_y^2(i, j))} \right) + \frac{\pi}{2} \quad (11)$$

The image is enhanced by the Gaussian low-pass filter followed by the 2-D Gabor filter [38]. Let f_0 denote the ridge frequency, θ the orientation of the filter, σ_x and σ_y standard deviations of the Gaussian envelope along the x and y axes, and $[x_\theta, y_\theta]$ coordinates of $[x, y]$ after the clockwise rotation of the Cartesian axes by $0.5\pi - \theta$. The 2-D Gabor filter is given by:

$$G(x, y, \theta, f_0) = e^{-\frac{1}{2} \left(\frac{x_\theta^2}{\sigma_x^2} + \frac{y_\theta^2}{\sigma_y^2} \right)} \cos(2\pi f_0 x_\theta) \quad (12)$$

$$x_\theta = x \sin \theta + y \cos \theta \quad (13)$$

$$y_\theta = -x \cos \theta + y \sin \theta \quad (14)$$

As minutiae extraction algorithms operate on binary images, the filtering output is binarized. Gray level of each pixel is compared to a global threshold, resulting in the image with two levels of interest: ridges (black pixels) and valleys (white pixels). Morphological operators are further applied to the binarized image in order to eliminate noise resulting from spurs and line breaks. The thinning algorithm presented by Lam *et al.* [39] reduces the width of ridge lines. The image is segmented into two subfields as in the checkboard pattern. Let $p_1, p_2, \dots, p_8 \in [0, 1]$ denote neighbor pixels of pixel p as shown in Figure 4, and let $b_i=1$ if:

$$p_{2i-1} = 0 \wedge (p_{2i} = 1 \vee p_{2i+1} = 1) \quad (15)$$

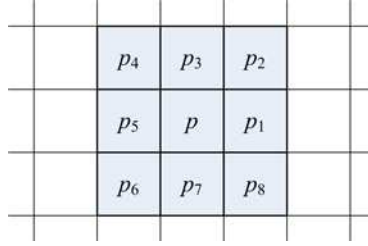


Figure 4

Eight neighbor pixels of p in a binarized image

Crossing number $X_H(p)$, according to the definition of Hilditch, is the number of times one crosses from white to black point when points are traversed in order. Four pixel removal conditions used in the iterations of the algorithm are defined as follows:

$$X_H(p) = \sum_{i=1}^4 b_i = 1 \quad (16)$$

$$2 \leq \min \left\{ \left(\sum_{i=1}^4 p_{2i-1} \vee p_{2i} \right), \left(\sum_{i=1}^4 p_{2i} \vee p_{2i+1} \right) \right\} \leq 3 \quad (17)$$

$$(p_2 \vee p_3 \vee \overline{p_8}) \wedge p_1 = 0. \quad (18)$$

$$(p_6 \vee p_7 \vee \overline{p}) \wedge p_5 = 0. \quad (19)$$

The condition $X_H(p)=1$ implies that p is a contour point [39]. Each iteration of the algorithm has two sub-iterations. Pixel p is deleted from the first subfield in the first sub-iteration only if conditions (16), (17) and (18) are satisfied. The pixel p is deleted from the second subfield in the second sub-iteration only if conditions (16), (17) and (19) are satisfied. The result of the algorithm is an image composed of one pixel wide ridges, with clearly visible ridge terminations and bifurcation points (valley endings). Crossing number $X_R(p)$ is calculated for each pixel in the resulting image, according to definition of Rutovitz, as the number of transitions from white to black and vice versa when points in are traversed in order. The pixel p is identified as ridge termination point if:

$$X_R(p) = \sum_{i=1}^8 |p_{i+1} - p_i| = 2 \quad (20)$$

The pixel p is identified as bifurcation point if:

$$X_R(p) = \sum_{i=1}^8 |p_{i+1} - p_i| = 6 \quad (21)$$

4.3 Cancelable Template Generation

Non-invertible transforms are used to preserve the privacy of biometric templates. The transform produces a cancelable template that does not match the original and the original cannot be reconstructed from the cancelable template. If the stored template is compromised, a new cancelable template is generated by changing distortion characteristics of the non-invertible transform. The transformation applied to a fingerprint template is invertible if the post-transformation minutiae positions after are highly correlated to minutiae positions before transformation [21]. According to the aforementioned statement, the goal of the transform is to eliminate minutiae correlation to the maximum possible extent. Additionally, tolerance to brute force attacks is required.

Let (x_i, y_i) , $i=1, \dots, n$ denote the coordinates of minutiae i for n identified minutiae points. The two-dimensional vector of extracted minutiae points is given by:

$$F = \{(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)\} \quad (22)$$

The non-invertibility of proposed transformation comes from cell shuffling. The coordinate system is divided into $N_x \times N_y$ cells, each containing n_{xy} minutiae points. Cells are shuffled as follows: circular shift right is performed to each cell according to the number of minutiae in that cell. Once horizontal shifting is finished, circular shift down is performed in the same manner. More than one cell can be mapped into the same cell after the transformation, as shifting depends on the number of points in the cell and no key is employed as a transformation matrix. The transform is non-invertible at this point, as is impossible to determine the original cell of the minutiae. This transform also satisfies the condition of local smoothness. The strength of the transform depends on the number of cells: an adversary performing brute force attack would have to try $(N_x N_y)^{N_x N_y}$ possibilities. For example, brute force attack against 4x4 cells shifting transform would require 18.5×10^{18} attempts, and against 4x5 cells transform 1.05×10^{26} attempts.

Let (x_i^T, y_i^T) , $i=1, \dots, n$ denote the coordinates of minutiae i after cell shuffling. Generated cancelable template is given by:

$$F^T = \{(x_1^T, y_1^T), (x_2^T, y_2^T), \dots, (x_n^T, y_n^T)\}. \quad (23)$$

Templates are matched in the operating phase by discarding missing points, calculating the sum of the squared differences between two vectors, normalized by the number of remaining non-discarded values, and comparing the matching score with a threshold.

4.4 Experimental Evaluation

The implementation of the proposed framework is experimentally evaluated using MATLAB (version R2011b). As this research does not deal with acquisition hardware, images from CASIA-IrisV4 and CASIA-FingerprintV5 [40], collected by the Chinese Academy of Sciences' Institute of Automation, are used as inputs. It should be noted that different implementation of the proposed framework (different employed modalities, algorithms or parameters) will result in different error rates, key generation template entropy and cancelable template security.

The iris image subset used in our experiments consists of 500 samples from 50 subjects. Each iris image is normalized into an 8-bit 240x20 pixel image, and a 1-D log-Gabor filter with $\sigma=0.5$ and 12 pixel center wavelength is subsequently applied, resulting in a 9600 bit template. These parameters were found to provide high local entropy and optimum encoding on CASIA database [41]. Fingerprint image subset used in our experiments also consists of 500 samples from 50 subjects, with a resolution of 328x356 pixels. The optimal number of cells used in the non-invertible transform is selected as a compromise between the template security to brute force attacks and Equal Error Rate (EER), as presented in Fig. 5.

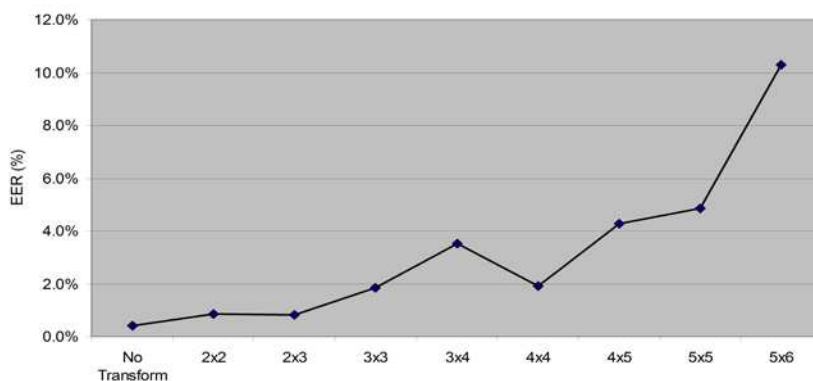


Figure 5

Determining optimal number of cells used in non-invertible transform

According to Figure 5, the optimal number of cells used in non-invertible transform is 4x4, resulting in less than 2% EER (1 reject in 50 authentication attempts) and the sufficient level of biometric template security. Five look-up tables are initially generated for different key lengths, each containing 50 rows of key hashes, correction codes from the Reed-Solomon algorithm output and cancelable templates generated from one fingerprint image for each subject. System was further tested as follows: FAR and FRR rates for different key sizes, without hash verification, are given in Table 1 and the overall system-wide performance is given in Table 2. Tolerance to brute force attacks takes into

account the fact that an adversary knows the length of the key. Otherwise, they would have to seek hash collision, which would make an attack even more complicated if the hash produces digest larger than the key.

Table 1

Average FAR and FRR for different key lengths (key generation without hash verification)

Key length	FAR (%)	FRR (%)
128	0.04%	0.31%
160	< 0.01%	1.29%
192	0%	4.01%
224	0%	11.52%
256	0%	14.83%

Table 2

System-wide performance for different key lengths and optimal number of cells (4x4)

Key length	Hash	Security (brute force)	FAR (%)	FRR (%)
128	RIPEMD-160	6.29×10^{57}	0%	2.62%
160		2.70×10^{67}		3.83%
192	SHA-224	1.61×10^{77}		6.75%
224		4.99×10^{86}		13.41%
256	SHA-256	2.14×10^{96}		15.97%

Conclusions

Although lower error rates, generated by other systems, are reported in the literature, no system that generates a 100% stable cryptographic key with a 0% false acceptance rate is reported, to the best of our knowledge. According to the experimental evaluation of the proposed implementation, that employs iris and fingerprint biometrics, as well as conventional key generation and authentication methods, the system will falsely identify one out of 38 users as an impostor while generating a 128 bit key and one out of 6 users while generating a 256 bit key. Although these error rates might not be suitable while attempting to generate the key that will, for example, open the classroom or office door, they are more than acceptable in critical environments where false acceptance may result in severe consequences, while the legitimate users are allowed to retry. Furthermore, the system protects stored identities with cancelable biometrics and is resistant to all attack types, with the exception of indiscriminate availability violations, as it is discussed in section 3.1. If the system generates a 128-bit key, an adversary trying to perform a brute force attack would have to try 6.29×10^{57} possibilities, while for the 256-bit key the number of possibilities increase to 2.14×10^{96} .

To conclude, the main contribution of the proposed framework is stable generated key, robustness, biometric template privacy and 0% false acceptance rate.

Our further research in biometric cryptosystems will be focused on the implementation of the iris-face key generation system according to the framework presented in this paper and the reduction of false rejection rates.

References

- [1] A. K. Jain, A. Ross: Introduction to Biometrics. In “Handbook of Biometrics”, A. Jain et al. (Eds), Springer, 2008
- [2] Y. C. Feng, P. C. Yuen, A. K. Jain: A Hybrid Approach for Face Template Protection. In Proceedings of SPIE Conference of Biometric Technology for Human Identification, Orlando, USA, Vol. 6944, pp. 325, 2008
- [3] P. Balakumar, R. Venkatesan: A Survey on Biometrics-based Cryptographic Key Generation Schemes. International Journal of Computer Science and Information Technology & Security, Vol. 2, No. 1, pp. 80-85, 2012
- [4] A. K. Jain, A. Ross, S. Prabhakar: An Introduction to Biometric Recognition. IEEE Transactions on Circuits and Systems for Video Technology, Vol. 14, pp. 4-20, 2004
- [5] B. Biggio: Adversarial Pattern Classification. Doctoral dissertation, University of Cagliari, Cagliari, Italy, 2010
- [6] A. Jagadeesan, K. Duraiswamy: Secured Cryptographic Key Generation From Multimodal Biometrics: Feature Level Fusion of Fingerprint and Iris. International Journal of Computer Science and Information Security, Vol. 7, No. 2, pp. 28-37, 2010
- [7] L. Hong, A. K. Jain, S. Pankanti: Can Multibiometrics Improve Performance? In Proceedings of IEEE Workshop on Automatic Identification Advanced Technologies, pp. 59-64, NJ, USA, 1999
- [8] A. K. Jain, A. Ross: Multi-Biometric Systems: Special Issue on Multimodal Interfaces that Flex, Adapt, and Persist. Communications of the ACM, Vol. 47, No. 1, pp. 34-40, 2004
- [9] A. K. Jain, K. Nandakumar, A. Nagar: Biometric Template Security. EURASIP J. Adv. Signal Process, 2008:1-17, 2008
- [10] J. Galbally, C. McCool, J. Fierrez, S. Marcel, J. Ortega-Garcia. On the Vulnerability of Face Verification Systems to Hill-Climbing Attacks. Pattern Recogn., 43(3) pp. 1027-1038, 2010
- [11] S. Prabhakar, A. Jain: Decision-Level Fusion in Fingerprint Verification. Pattern Recognition, Vol. 35, pp. 861-874, 2002
- [12] Z. Wang, E. Wang, S. Wang, Q. Ding: Multimodal Biometric System Using Face-Iris Fusion Feature. Journal of Computers, Vol. 6, No. 5, pp. 931-938, 2011

- [13] K. Toh, J. Kim, S. Lee: Biometric Scores Fusion Based on Total Error Rate Minimization. *Pattern Recognition*, Vol. 41, pp. 1066-1082, 2008
- [14] A. Ross, R. Govindarajan: Feature Level Fusion in Biometric Systems. In *proceedings of Biometric Consortium Conference*, September 2004
- [15] G. I. Davida, Y. Frankel, B. J. Matt: On Enabling Secure Applications through Off-Line Biometric Identification. In *Proceedings of the IEEE Symposium on Privacy and Security*, pp. 148-157, 1998
- [16] Y. J. Chang, W. Zhang, T. Chen: Biometrics-based Cryptographic Key Generation. In *Multimedia and Expo, 2004. ICME'04. 2004 IEEE International Conference on* (Vol. 3, pp. 2203-2206) IEEE
- [17] A. Juels, M. Sudan: A fuzzy vault scheme. In *Proc. IEEE Int. Symp. Information Theory*, IEEE Press, p. 408, 2002
- [18] Y. Dodis, L. Reyzin, A. Smith: Fuzzy Extractors: How to Generate Strong Keys from Biometrics and Other Noisy Data. In *Proceedings of the Eurocrypt 2004*, pp. 523-540, 2004
- [19] P. Tuyls, A. Akkermans, T. Kevenaar, G-J. Schrijen, A. M. Bazen, R. Veldhuis: Practical Biometric Authentication with Template Protection. In *Proc. of 5th Int. Conference on Audio- and Video-based Person Authentication (AVBPA)* pp. 20-22, 2005
- [20] K. H. Solanki, C. Patel: Biometric Key Generation in Digital Signature of Asymmetric Key Cryptographic To Enhance Security Of Digital Data. In *International Journal of Engineering Research and Technology*, Vol. 2, No. 2, 2013. ESRSA Publications
- [21] N. K. Ratha, S. Chikkerur, J. H. Connell, R. M. Bolle: Generating Cancelable Fingerprint Templates. *Pattern Analysis and Machine Intelligence*, IEEE Transactions on, 29(4), pp. 561-572, 2007
- [22] R. Ang, R. Safavi-Naini, L. McAven.: Cancelable Key-based Fingerprint Templates. In C. Boyd & J. Gonzalez Nieto (Eds.), *Australasian Conference on Information Security and Privacy*, pp. 242-252, 2005
- [23] F. Hao, R. Anderson, J. Daugman: Combining Crypto with Biometrics Effectively. *IEEE Transactions on Computers*, Vol. 55, pp. 1081-1088, 2006
- [24] K. Bae, S. Noh, J. Kim: Iris Feature Extraction using Independent Component Analysis, 4th International Conference on Audio- and Video-based Biometric Person Authentication, Guildford, UK, pp. 838-844, 2003
- [25] L. Wu, X. Liu, S. Yuan, P. Xiao: A Novel Key Generation Cryptosystem based on Face Features. In *Signal Processing (ICSP) 2010 IEEE 10th International Conference on*, pp. 1675-1678. IEEE

- [26] R. Sashank Singhvi, S. P. Venkatachalam, P. M. Kannan, V. Palanisamy: Cryptography Key Generation using Biometrics. International Conference on Control, Automation, Communication and Energy Conservation (INCACEC), pp. 1-6, 2009
- [27] J. Ban, M. Féder, M. Oravec, J. Pavlovičová: Non-Conventional Approaches to Feature Extraction for Face Recognition. Acta Polytechnica Hungarica, Vol. 8, No. 4, pp. 75-90, 2011
- [28] P. Balakumar, R. Venkatesan: Combining Biometric Features of Iris and Retina for Better Security Cryptography. Digital Image Processing, 3(16), 1083-1089, 2011
- [29] A. S. Gokulakumar, C. Venkataraghavan., S. Kavya Priya, T. Suganya: Encryption of Cryptographic Key Technique by Crossover of Iris and Face Biometric Key. International Journal of Innovative Research in Computer and Communication Engineering, Vol. 2, Special Issue 1, pp. 354-362, 2014
- [30] M. Barreno, B. Nelson, R. Sears, A. D. Joseph, J. D. Tygar: Can Machine Learning be Secure? In Proc. of the 2006 ACM Symposium on Information, computer and communications security (pp. 16-25) ACM, 2006
- [31] G. Amoli, N. Thapliyal, N. Sethi: Iris Preprocessing. International Journal of Advanced Research in Computer Science and Software Engineering, Vol. 2, No. 6, pp. 301-304, 2012
- [32] D. J. Kerbyson, T. J. Atherton: Circle Detection using Hough Transform Filters, Fifth International Conference on Image Processing and its Applications, Edinburgh, UK, 04 – 06 July 1995, pp. 370-374
- [33] R. P. Wildes: Iris Recognition: an Emerging Biometric Technology. Proceedings of the IEEE, 85(9) pp. 1348-1363, 1997
- [34] J. Daugman: How iris recognition works. Circuits and Systems for Video Technology, IEEE Transactions on, 14(1) pp. 21-30, 2004
- [35] D. J. Field: Relations between the Statistics of Natural Images and the Response Properties of Cortical Cells. Journal of the Optical Society of America, Vol. 4, No. 12, 1987
- [36] H. Furuya, S. Eda, T. Shimamura: Image Restoration via Wiener filtering in the Frequency Domain. WSEAS transactions on signal processing, 5(2), pp. 63-73, 2009
- [37] Y. Wang, J. Hu, F. Han: Enhanced Gradient-based Algorithm for the Estimation of Fingerprint Orientation Fields. Applied Mathematics and Computation, Special Issue on Intelligent Computing Theory and Methodology, Vol. 185, No. 2, pp. 823-833, 2007

- [38] D. Maltoni, D. Maio, A. K. Jain, S. Prabhakar: Handbook of Fingerprint Recognition, Springer-Verlag, 2003
- [39] L. Lam, S. W. Lee, C. Y. Suen: Thinning Methodologies - a Comprehensive Survey. IEEE Transactions on pattern analysis and machine intelligence, 14(9), pp. 869-885, 1992
- [40] Biometrics Ideal Test, <http://biometrics.idealtest.org>
- [41] S. Adamović, M. Milosavljević: Information Analysis of Iris Biometrics for the Needs of Cryptology Key Extraction. Serbian Journal of Electrical Engineering, Vol. 10, No. 1, pp. 1-12, 2003

Fatigue Failure Analysis for Bolt-Nut Connections having Slight Pitch Differences using Experimental and Finite Element Methods

Xin Chen^{1,2}, Nao-Aki Noda¹, Magd Abdel Wahab², Yu-Ichiro Akaishi¹, Yoshikazu Sano¹, Yasushi Takase¹, Gusztáv Fekete³

¹ Department of Mechanical Engineering

Kyushu Institute of Technology, Kitakyushu 804-8550, Japan

xin.chen@ugent.be, noda@mech.kyutech.ac.jp, o344144r@mail.kyutech.jp

sano.yoshikazu029@mail.kyutech.jp, takase@mech.kyutech.ac.jp

² Department of Mechanical Construction and Production

Faculty of Engineering and Architecture, Ghent University

Technologiepark Zwijnaarde 903, B-9052 Zwijnaarde, Belgium

magd.abdelwahab@ugent.be

³ Department of Mechanical Engineering, Savaria Institute of Technology,

Faculty of Natural and Technical Sciences, University of West Hungary

Károlyi Gáspár tér 4, H-9700 Szombathely, Hungary

fekete.gusztav@ttk.nyme.hu

Abstract: In this paper, fatigue failure is considered, for bolt-nut connections, when a slight pitch difference is introduced between the bolt and the nut. To improve the fatigue life, three types of pitch difference are produced on the specimens and the experimental results are compared and discussed in terms of FEM analysis. Considering the standard bolt-nut connection of $\alpha=0\ \mu\text{m}$, the bolt fracture does not happen at the No. 1 thread by introducing a slight pitch difference of $\alpha=5\ \mu\text{m}$ and $\alpha=15\ \mu\text{m}$, as observed from the experiments. Furthermore, it is found that the fatigue life can be extended by introducing suitable pitch differences. The effect of bolt-nut fitted clearance, on the fatigue failure is also investigated.

Keywords: Bolt-Nut Connection; Fatigue Fracture; Pitch Difference; Finite Element Method; Fitting Clearance

1 Introduction

The bolt-nut connections can be regarded as one of the most important material joining techniques. They are widely used in various engineering fields, including aerospace, automotive and mechanical/civil engineering constructions. To ensure the structures safety, high fatigue strength has been required, as well as, anti-loosening performance. Most previous studies are focusing on the anti-loosening performance for newly developed bolt-nut connections [5, 8, 19, 23]. Only a few studies contribute toward improving fatigue strength. This is probably because the high stress concentration factors, $K_t=3-5$, which always occur at the root of bolt thread. It is not easy to improve fatigue strength for standard bolt-nut connections.

During the last few decades, many investigations related to the fatigue life of bolt-nut connections have been carried out by using the fundamental experimental methods. Yakushev [24] investigated the effect of manufacturing technology on the fatigue strength of thread connections. His work showed that the rolled thread improves the fatigue strength significantly compared with the cut thread and grinded thread. Majzoobi et al. [13] studied the thread pitch and found that ISO standard coarse threaded bolts have a higher fatigue life than the fine threaded bolts. Nishida [16] discussed the effect of type of thread on the fatigue life of screws, including triangular thread, trapezoidal thread, positive buttress thread and negative buttress thread. It was found that the traditional triangular thread has an excellent total balance when considering fatigue strength and machinability. Nishida also proposed the tapered bolt, named CD bolt (Critical Design for Fracture), which has been confirmed that the new profile approximately doubles the fatigue strength of bolts as compared to the traditional profiles [15,18]. Hirai and Uno [6] developed a new super high tension bolt by considering the R-r shape thread, which has two different radii at the bottom of bolt thread. It was shown that the stress concentration factor could be reduced to 60% of the conventional high tension bolt thread.

In addition to the shape of bolt thread, some studies also paid attention to the effects of the tightening or loading conditions on the fatigue life of bolted joints. Suzuki et al. and Kawano et al. [9, 22] reported the fatigue characteristics of bolted joints tightened in elastic and plastic regions. Hobbs et al. [7] discussed the effect of eccentric loading on the fatigue performance of high-tensile bolts.

Many numerical methods have been developed to analyze the failure mechanism of some structure [12]. For the research of bolt-nut, the analytical and numerical methods have also been applied to clarify the stress along the bolt threads. It is evident that the fatigue strength of the bolt is largely influenced by the stress concentration at the first root of the bolt thread which carries most of the load. Bickford [1] provided a broad-based review of the factors affecting the design, assembly and behavior of bolted joints.

Kenny and Patterson [10, 11, 21] studied the load and stress distribution in a bolt-nut connector by using 3-D frozen-stress photoelastic analysis and compared their results with theoretical and numerical solutions. They also fully reviewed the distribution of the load between the engaging threads.

In the simulation studies, the three-dimensional bolt-nut assemblies can be simply analyzed by the axisymmetric model, to calculate the load and stress distribution along the bolt threads. Axisymmetrical finite element analyses have been studied in some literature [2, 4]. Chen [3] compared the load thread distribution results by using the axisymmetric model and the three-dimensional model. Then, he concluded that the axisymmetric model may provide a good estimation because the helical thread effect is not very large. Hua Zhao [25] developed the virtual contact loading method to study the load distributions along the threads in a three-dimensional bolt-nut connector. Maruyama [14] investigated the thread pitch error and the loaded flank angle error by applying both of the finite element method and the copper-electroplating method. He found that the pitch adjustment affects larger than the flank angle adjustment for improving the fatigue strength. Previously one of the authors analyzed the tapered threads with the finite element method based on the proposal by Nishida, and discussed the stress reduction effect of the tapered thread under several geometrical conditions [20].

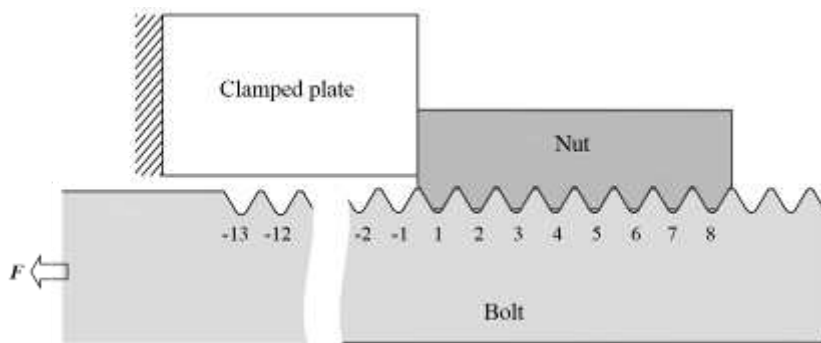
To improve the fatigue life of the bolt, the key is how to deal with the non-uniform loading along the bolt threads, as well as, reducing the high stress concentration at the root of the thread. In this study, a slight pitch difference is introduced between bolt and nut. In order to study the fatigue fracture in bolt-nut connection, fatigue experiments are conducted for specimens having three types of pitch differences α , i.e. $\alpha=0\text{ }\mu\text{m}$, $\alpha=5\text{ }\mu\text{m}$ and $\alpha=15\text{ }\mu\text{m}$, where $\alpha=0\text{ }\mu\text{m}$ represents the standard bolt-nut connections. The fatigue life will be discussed focusing on the fracture positions of those specimens. To clarify the effect of pitch difference, the axisymmetrical model is created by Finite Element Method (FEM) to analyze the contact status and the stresses in threads. The effect of a fitting clearance also will be discussed considering the contact status between the actual bolt-nut connection threads.

2 Fatigue Experiment to Investigate the Fatigue Life

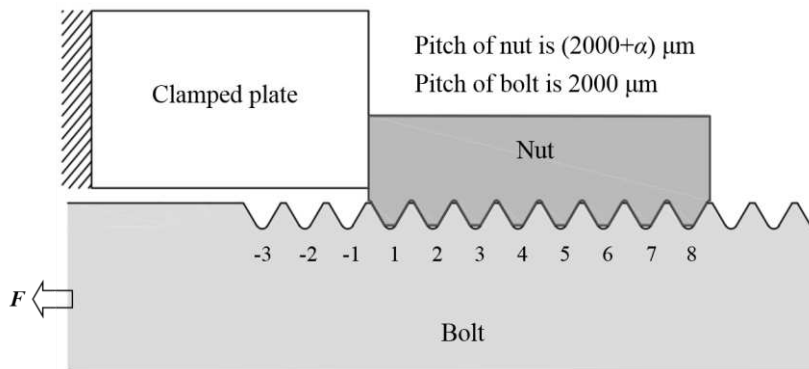
In this study, the Japanese Industrial Standard (JIS) M16 bolt-nut connections with strength grade 8.8 are employed. The bolt material is chromium-molybdenum steel SCM435, and the nut material is medium carbon steel S45C quenched and tempered. The standard M16 bolt-nut connection has the same pitch dimension of $2000\text{ }\mu\text{m}$, here, the nut pitch is assumed to be equal or slightly larger than the bolt pitch (see Fig. 1 (c), (d)). Three types of pitch differences, namely $\alpha=0\text{ }\mu\text{m}$, $\alpha=5\text{ }\mu\text{m}$ and $\alpha=15\text{ }\mu\text{m}$, are considered in this study. The clearance

between bolt and nut is assumed as a standard dimension, i.e. $125\ \mu\text{m}$. The bolt is made by rolling, which is usually used, and the nut threads is manufactured by cutting to improve the thread accuracy instead of by tapping, which is usually used. The tolerance class of bolt and nut is 6 H/6 g (JIS).

Fig. 1 shows the schematic diagram of bolt-nut connection. As shown in Fig. 1, in the experimental model, No.-13 is the starting thread, and in the analytical model, No.-3 bolt thread is the starting thread. In this paper, the thread number of Fig. 1 (b) will be used. Therefore, No.-3 thread used in this paper is the starting thread referring to No.-13 thread in the experimental specimen. Fig. 1 (c), (d) explains why the nut pitch should be larger. If the nut pitch is larger than the bolt pitch, at No. 1 thread left side surface contact before the loading is changed to no contact after the loading. However, if the nut pitch is smaller than the bolt pitch, the right side contact surface of No.1 thread before the loading is not changed and the contact force just becomes larger than the contact force of normal bolt-nut connection after the loading. Therefore, the largest stress concentration at No. 1 thread can be reduced only by the larger nut pitch.



(a) Experimental specimen (Considering Fig. 1 (b), No.-3 is used in this paper as the starting thread instead of No.-13)



(b) Analytical model (In this paper No.-3 is used as the starting thread referring to No.-13 in Fig. 1 (a))

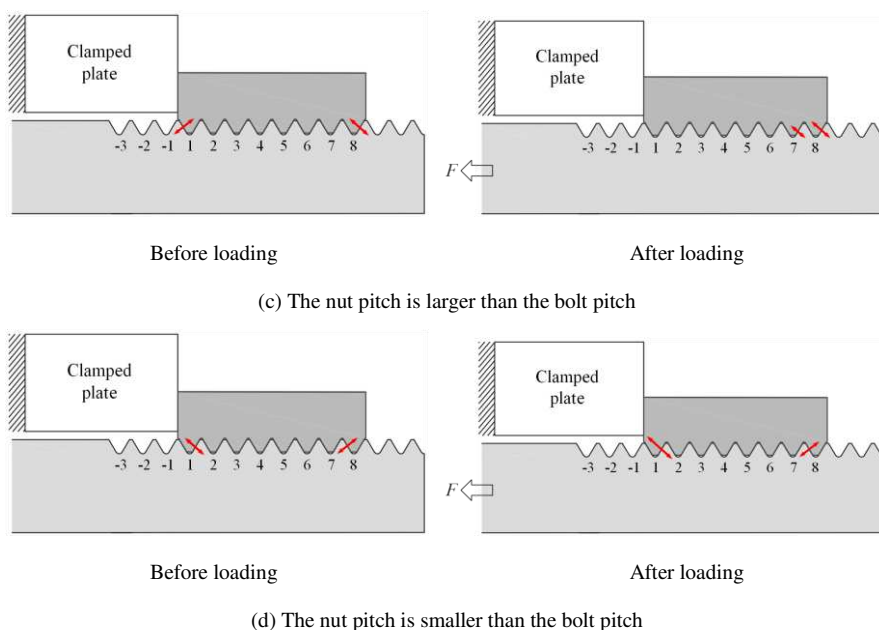


Figure 1

Schematic illustration of bolt-nut connection

The 60 tonf Servo Fatigue Testing Machine with cycling frequency of 9 Hz is used in this experiment. The assembly drawing is illustrated in Fig. 2. In the first place, the fatigue experiment is performed for the specimen of $\alpha=15\ \mu\text{m}$, which is subjected to an axial force of $F=30\pm14.1\ \text{kN}$. Since the cross sectional area of the bolt $A_R=141\ \text{mm}^2$, the corresponding stress amplitude is 100 MPa. After repeated 1.94×10^5 stress cycles, fracture does not happen. This experiment is conducted to investigate the fatigue life until the fracture with confirming the fracture position of the specimens under different pitch differences. To obtain the results in a short time, therefore, the fatigue load was changed to $F=30\pm18.3\ \text{kN}$, for which the corresponding stress amplitude increased to 130 MPa. Under this loading, the fatigue experiment continues for another 2×10^5 cycles, where the fracture happens. In the case of $\alpha=0\ \mu\text{m}$, under the load of $F=30\pm18.3\ \text{kN}$ the fracture happened at 2.19×10^5 cycles, and for $\alpha=5\ \mu\text{m}$, the fracture happens at 2.71×10^5 cycles under the same loading conditions.

Fig. 3 shows the fracture positions of the three different specimens. For the standard bolt-nut connection ($\alpha=0\ \mu\text{m}$), the fracture happens at the first bolt thread. However, for $\alpha=5\ \mu\text{m}$ and $\alpha=15\ \mu\text{m}$, fracture happens at thread No.-3 (see Fig. 3 and Fig. 1).

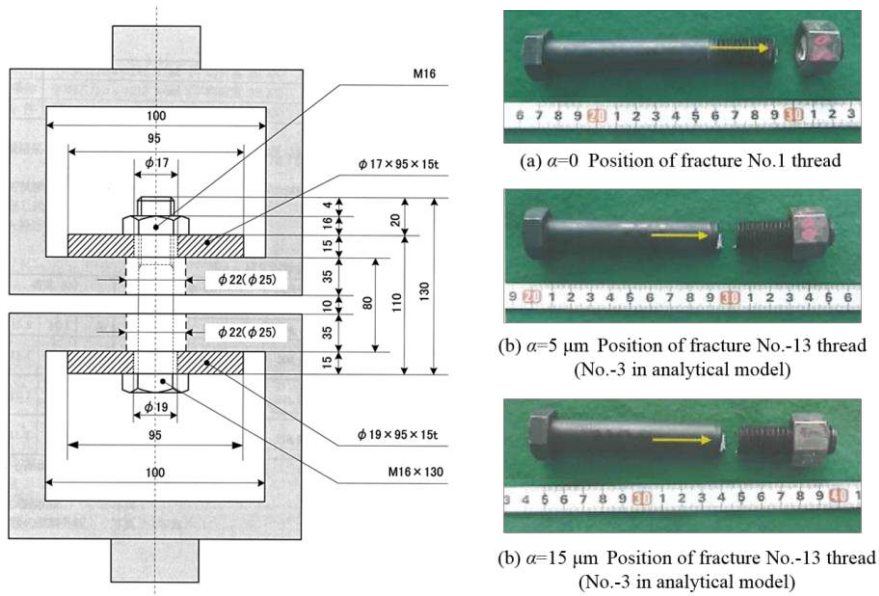


Figure 2 and Figure 3
Fatigue experiment device (dimensions in mm) – Fractured specimens

Utilizing a similar fatigue experimental result [17], the slope of $S-N$ curves for $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$ are depicted in Fig. 4. Then, Miner's rule is applied to calculate the equivalent fatigue life of $\alpha=15 \mu\text{m}$ under the load of $F=30 \pm 18.3 \text{ kN}$, and the result is shown in Table 1. It can be seen that the fatigue lives of $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$ are longer than that of $\alpha=0 \mu\text{m}$. Among the three specimens, the specimen of $\alpha=5 \mu\text{m}$ has the longest fatigue life.

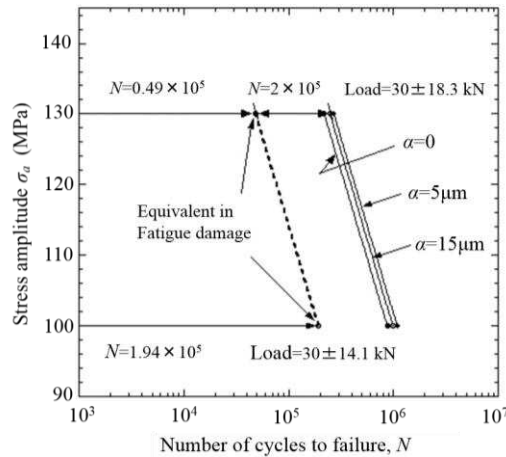


Figure 4
 $S-N$ curve

It should be noted that the stress concentration at No.-3 thread can be reduced easily to avoid the fracture by changing No.-3 thread shape because of no contact of the nut. Thus, for $\alpha=5\text{ }\mu\text{m}$ and $\alpha=15\text{ }\mu\text{m}$, a longer fatigue life can be expected by controlling the fracture from No.-3 to No. 1-No. 8.

Table 1
Results of fatigue experiment

Specimens	$\alpha=0\mu\text{m}$	$\alpha=5\mu\text{m}$	$\alpha=15\mu\text{m}$
Axial force F (kN)	30 ± 18.3		
Stress σ (MPa)	213 ± 130		
Number of cycles until fracture happen at No.1-8 threads	2.19×10^5	$>2.71\times 10^5$	$>2.49\times 10^{5*}$
Position of fracture	No.1 thread	No.-3 thread	No.-3 thread

* : Until the number of cycles= 1.94×10^5 $F=30\pm 14.1$ kN

3 Finite Element Method to Investigate the Stress Concentration

Fig. 5 shows the axisymmetric model of the bolt-nut connection created by using FEM code MSC.Marc/Mentat 2007. A cylindrical clamped plate is modeled with an inner diameter of 17.5 mm, outer diameter of 50 mm and thickness of 35 mm, whose inner diameter is nearly the same with the clamped body in the experimental device as shown in Fig. 2. The material of the clamped plate is SS41. Here, the Young's modulus is 206 GPa and the Poisson's ratio is 0.3 for all the materials of bolt, nut and clamped plate. The bolt, nut and clamped body are modeled as three contact bodies. Friction coefficient of 0.3 with Coulomb friction is used for the analysis. The clamped body is fixed in the horizontal direction, and load F is applied on the bolt head as shown in Fig. 5. A fine mesh is created at the root of bolt thread with the size of $0.015\text{ mm} \times 0.01\text{ mm}$, and 4-noded, axisymmetric solid, full integration element is used.

In the first place, in order to investigate the effect of friction, the stress concentration factor is calculated for $\alpha=0\text{ }\mu\text{m}$ by setting three different coefficient of friction, i.e. $\mu=0, 0.15$ and 0.3 , under an axial force of 30 kN. It is found that the friction effect is very small. In this study, therefore, the coefficient of friction is put equal to $\mu=0.3$. As the first step, elastic analysis is performed.

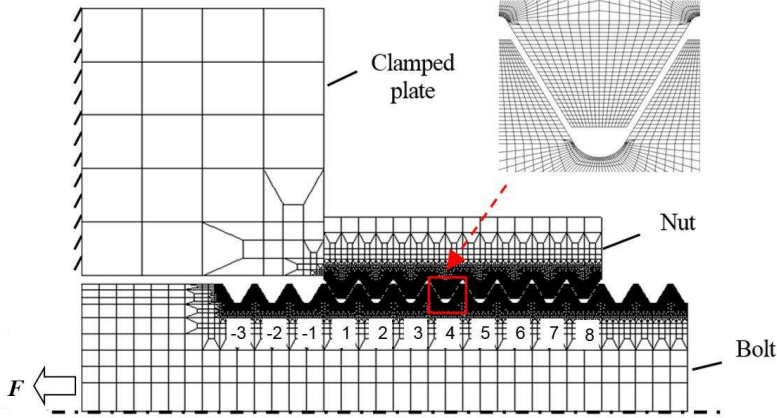


Figure 5

Axi-symmetric finite element model

In Fig. 5, it should be noted that the stress concentration at No. 1 is the most important because the final fracture happens at this thread. The stress concentration at No.-3 to No.-1 threads can be controlled and reduced by changing the thread shape because of no contact. For No. 7 or No. 8 threads, for example, the fracture at these threads does not mean the final fracture because other threads may carry the load. Nishida [17] has discussed the fatigue strength of bolt-nut connection in detail. He has indicated that the fatigue limit of bolts is far lower than that of conventional notched specimens. Therefore, the notch factor K_f of bolts should be considered as $K_f \approx K_t$ although usually $K_f < K_t$. Here, K_t is the stress concentration factor of bolts. To improve the fatigue strength of bolt-nut, the stress concentration at No.1 thread will be focused in this study, because the final fracture can be controlled to occur at this thread. Then, the effect of pitch difference on the stress concentration will be discussed.

3.1 Stress Concentration Factor

The stress concentration at the root of bolt thread is evaluated by using the stress concentration factor K_t defined by Eq. (1),

$$K_t = \frac{\sigma_{t\max}}{\sigma_n}, \quad \sigma_n = \frac{F}{A} \quad (1)$$

where $\sigma_{t\max}$ is the maximum tangential stress appearing at each bolt root, and σ_n is equal to the total bolt axial force F divided by the bolt cross section A_R as shown in Fig. 6. It should be noted that the total force F is always used for all threads to compare the severity at each thread in Fig. 7.

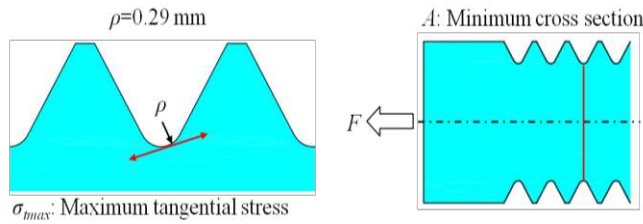


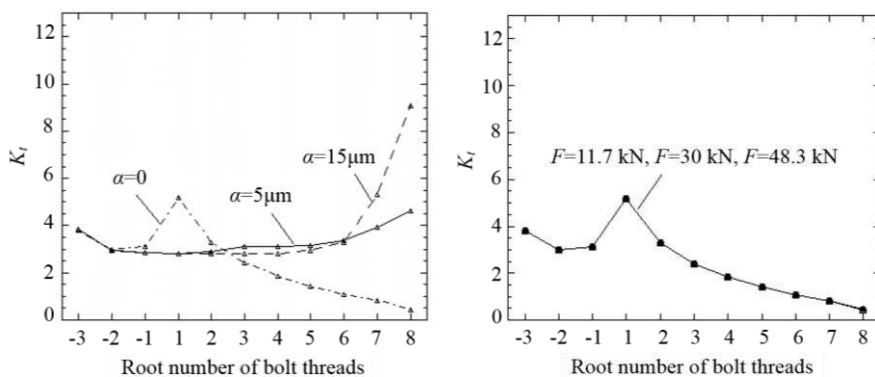
Figure 6
Definition of K_t

The K_t of each bolt root is indicated in Fig. 7 under the minimum load $F_{min}=30-18.3=11.7$ kN, mean load $F_{mean}=30$ kN and maximum load $F_{max}=30+18.3=48.3$ kN.

Fig. 7 (a) shows the comparison of the stress concentration factors K_t for $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$ under the same load of $F=30$ kN. It is found that when $\alpha=5 \mu\text{m}$ is introduced, the stress concentration at root No. 1 reduces significantly. However, the stress concentration at roots No. 7 and No. 8 increases largely when $\alpha=15 \mu\text{m}$.

Fig. 7 (b) (c) (d) shows the stress concentration factors of each bolt root under different loads for $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$. For the standard bolt-nut connection, with increasing the load, the stress concentration factor K_t at each root does not change. In the case of $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$, however, with increasing the load the stress concentration K_t at No. 8 decreases sharply.

It can be imagined that when the pitch difference is introduced the contact status between bolt threads and nut threads varies depending on the applied load. To make this point clear, the contact status of bolt and nut threads will be analyzed in the next section.



(a) $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$ under $F=30$ kN

(b) $\alpha=0 \mu\text{m}$

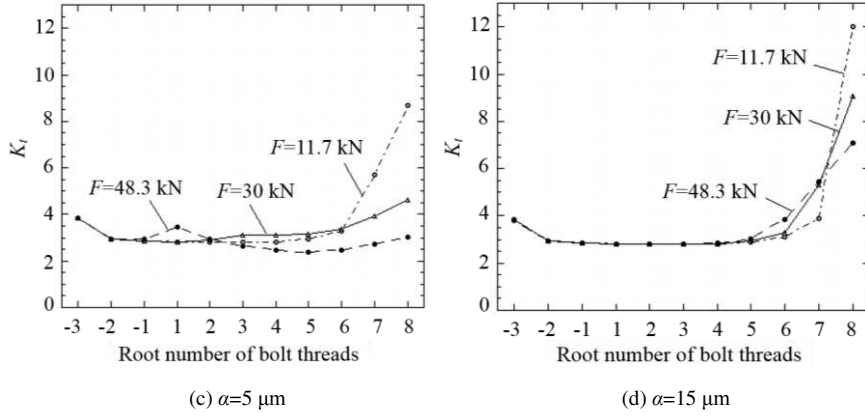


Figure 7

Stress concentration factor K_t at the root of bolt thread

3.2 Contact Status of Bolt-Nut Connection

The experimental load of $F=30\pm 18.3$ kN is applied to the models of $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$. Before analyzing the stress state, the effect of pitch difference on the contact status of bolt and nut threads is investigated. Fig. 8 shows the total number of contact threads between bolt and nut with increasing the load from $F_{min}=11.7$ kN to $F_{max}=48.3$ kN. As shown in Fig. 8, for the standard bolt-nut connection ($\alpha=0 \mu\text{m}$), all the nut threads are in contact with bolt threads independent of the magnitude of the load.

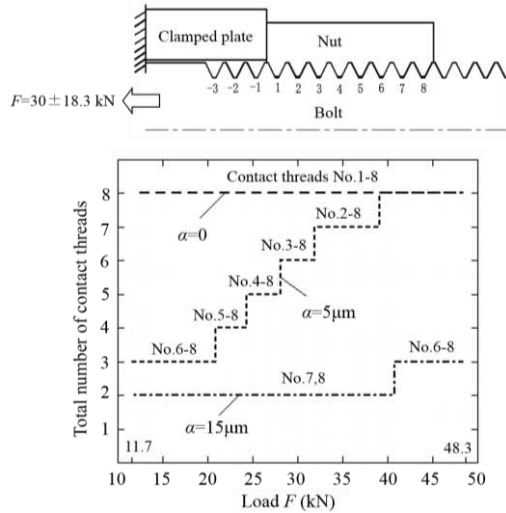


Figure 8

Total number of contact thread between bolt and nut for $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$

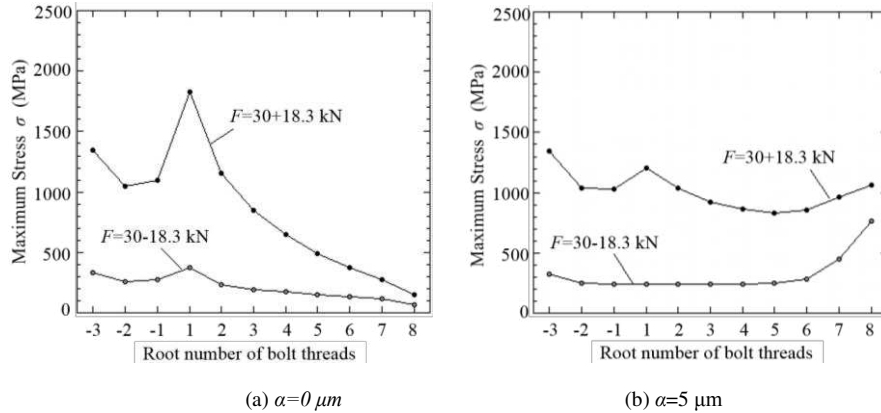
However, for $\alpha=5\ \mu\text{m}$, only three bolt threads, i.e., No. 6, No. 7 and No. 8, are in contact with nut threads under $F=F_{\min}$, although with increasing the load the contact thread number increases. When $F=F_{\max}$, the contact status becomes similar to the case of the standard bolt-nut connection. For $\alpha=\alpha_{\text{middle}}$ under $F=F_{\min}$, only bolt threads No. 7 and No. 8 are in contact with nut threads, and even under $F=F_{\max}$, only three bolt threads No. 6 to No. 8 are in contact with nut threads.

3.3 Mean Stress and Stress Amplitude at the Root of Bolt Thread

Fig. 9 shows the maximum stress, σ , at each root of bolt thread under different loads, i.e. $F_{\min}=30-18.3\ \text{kN}$ and $F_{\max}=30+18.3\ \text{kN}$. The endurance limit diagrams for $\alpha=0\ \mu\text{m}$, $\alpha=5\ \mu\text{m}$ and $\alpha=15\ \mu\text{m}$ are obtained as shown in Fig. 10, based on the results of Fig. 9. Herein, the mean stress σ_m and stress amplitude σ_a are defined in Eq. (2),

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2}, \quad \sigma_a = \frac{\sigma_{\max} - \sigma_{\min}}{2} \quad (2)$$

where σ_{\max} is the maximum stress of each thread under the maximum load $F=30+18.3\ \text{kN}$, and σ_{\min} is the maximum stress of each thread under the minimum load $F=30-18.3\ \text{kN}$. As shown in Fig. 10, the fatigue limit σ_w of the material SCM435 (JIS) is 420 MPa, and the yield stress σ_s is 800 MPa.



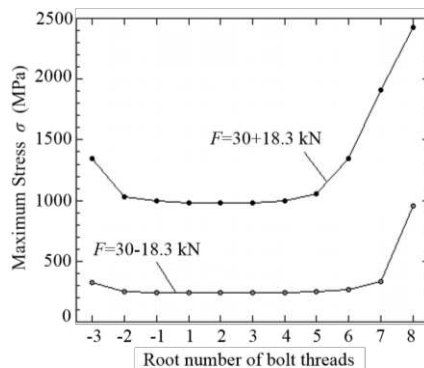
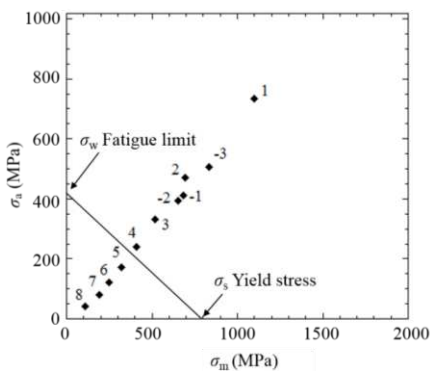
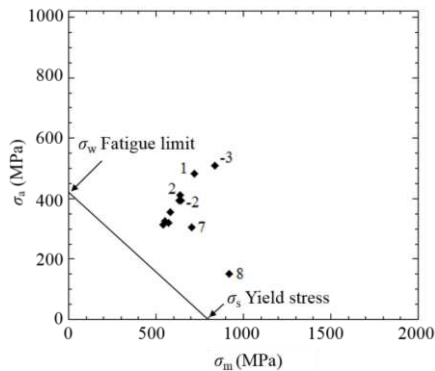
(c) $\alpha=15 \mu\text{m}$

Figure 9

Maximum stress σ at the root of bolt thread under different loads of $F=30-18.3 \text{ kN}$ and $F=30+18.3 \text{ kN}$

For the standard bolt-nut connection, the bolt thread No. 1 has the maximum stress amplitude as shown in Fig. 10 (a). On the other hand, for $\alpha=5 \mu\text{m}$ in Fig. 10 (b), it is seen that the stress amplitude, as well as, the mean stress at thread No. 1 decreases significantly. Compared with $\alpha=0 \mu\text{m}$, the difference of each thread severity becomes smaller, which reflects the uneven load sharing among the bolt threads is improved. For $\alpha=15 \mu\text{m}$ in Fig. 10 (c), the large stresses appear at threads No. 7 and No. 8 instead of thread No. 1. From Fig. 10, it is also found that when the pitch difference is large enough, threads No. 7 and No. 8 become the most dangerous threads instead of thread No. 1 although the fracture at No. 7 and No. 8 does not mean the final bolt fracture because other threads may carry the load.

(a) $\alpha=0 \mu\text{m}$ (b) $\alpha=5 \mu\text{m}$

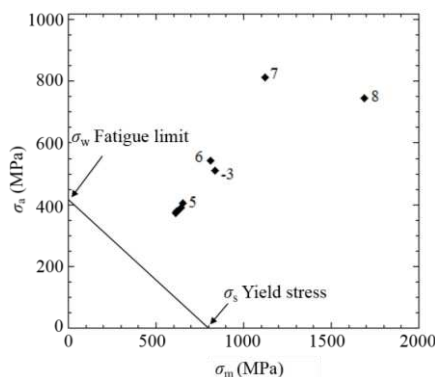
(c) $\alpha=15 \mu\text{m}$

Figure 10

Endurance limit diagrams for $\alpha=0 \mu\text{m}$, $\alpha=5 \mu\text{m}$ and $\alpha=15 \mu\text{m}$

Since the results of elastic analysis show that the maximum stress is far beyond the yield stress of 800 MPa for the bolt material SCM435 (JIS), the elastic-plastic analysis is also performed for the models of $\alpha=0 \mu\text{m}$ and $\alpha=15 \mu\text{m}$ under the same load of $F=30\pm 18.3 \text{ kN}$. Here, the same material of SCM435 is considered for both bolt and nut. Fig. 11 indicates the equivalent stress at bolt threads where the high stress appears for $\alpha=0 \mu\text{m}$ and $\alpha=15 \mu\text{m}$. For $\alpha=0 \mu\text{m}$, the plastic strain zone only occurs at the root of the No. 1 bolt thread. On the other hand, for $\alpha=15 \mu\text{m}$, the plastic strain appears at the root of No. 7 thread and the wide region of No. 8 thread. Fig. 11 shows that at No. 7 and No. 8 threads the fatigue cracks must initiate and propagate although those fractures do not mean the final bolt fracture because other No. 1-No. 6 threads can carry the load.

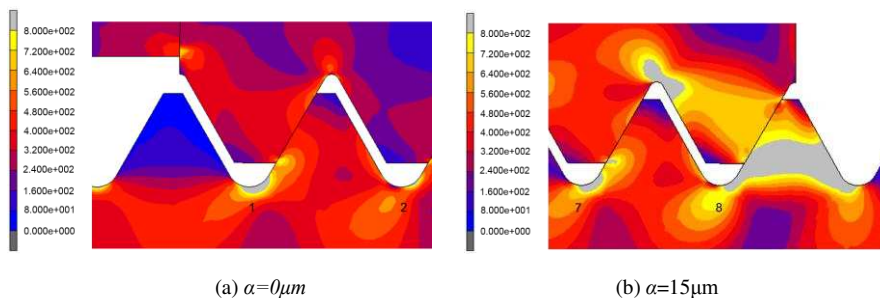
(a) $\alpha=0 \mu\text{m}$ (b) $\alpha=15 \mu\text{m}$

Figure 11

The equivalent stress in MPa under $F=30\pm 18.3 \text{ kN}$

Fig. 12 presents the endurance limit diagrams for $\alpha=0 \mu\text{m}$ and $\alpha=15 \mu\text{m}$ based on the elastic-plastic analysis considering the von-Mises stress at each bolt thread. Similarly to the results of elastic analysis, the difference of each thread severity becomes smaller for $\alpha=15 \mu\text{m}$ compared with $\alpha=0 \mu\text{m}$.

For $\alpha=0 \mu\text{m}$, the stress decreases significantly at No. 1 thread compared with the elastic analysis result. Similarly, for $\alpha=15 \mu\text{m}$, the stresses at No. 7 and No. 8 threads decrease significantly.

For the experimental result shown in Fig. 3(c), the fatigue fracture happens at No.-3 thread (=No.-13 in the experiment) for $\alpha=15 \mu\text{m}$. However, it is easy to reduce the stress concentration by changing No.-3 thread shape because of no contact of the nut. Once the fracture at No.-3 is avoided, for $\alpha=15 \mu\text{m}$, the real fracture or at least the initial crack may occur nearby No. 7 and No. 8 threads because the large strains appear as shown in Fig. 11.

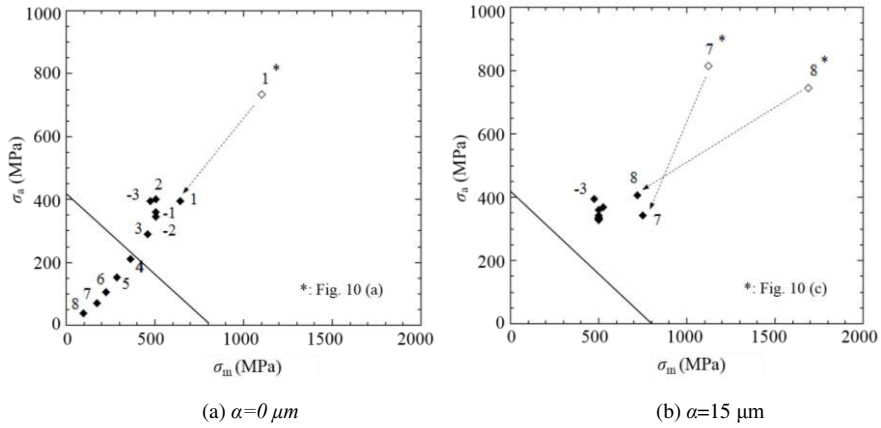


Figure 12
Endurance limit diagrams based on elastic-plastic analysis

4 Effect of the Bolt-Nut Clearance

As shown in Fig. 10 (a), (b) for $\alpha=0 \mu\text{m}$ and $\alpha=5 \mu\text{m}$, the most dangerous No. 1 and No.-3 bolt threads in the FEM analysis agrees with the experimental results in Fig. 3. However, as shown in Fig. 10 (c) and Fig. 3 (c) for $\alpha=15 \mu\text{m}$, the results of FEM and the results of the experiment do not coincide with each other. In other words, for $\alpha=15 \mu\text{m}$, the fracture happens at No.-3 bolt thread while the most dangerous position appears at No. 7 and No. 8 threads in the FE analysis. In future research, the effect of the clearance between the bolt and nut on the stress state of the bolt threads will be investigated.

In the above analysis, the clearance between the bolt and nut is assumed as a standard value, i.e. $125 \mu\text{m}$. The maximum clearance C_{\max} and the minimum clearance C_{\min} can be defined by Eq. (3) based on JIS:

$$C_{\max} = \frac{1}{2}(D_{\max}^{\text{nut}} - d_{\min}^{\text{bolt}}), C_{\min} = \frac{1}{2}(D_{\min}^{\text{nut}} - d_{\max}^{\text{bolt}}) \quad (3)$$

where D_{\max}^{nut} and D_{\min}^{nut} denote the maximum and minimum effective diameter of nut, respectively and d_{\max}^{bolt} d_{\min}^{bolt} denote the maximum and minimum effective diameter of bolt, respectively. From Eq. (3), for the M16 bolt-nut connection, the clearance ranges from 19 μm to 205 μm . However, the actual clearance can be determined by multiplying the maximum clearance by a factor ranged from 0.4 to 0.7. Thus, for M16 bolt-nut connections, the actual minimum and maximum clearance are $C_{\min}=205 \mu\text{m} \times 0.4=82 \mu\text{m}$ and $C_{\max}=205 \mu\text{m} \times 0.7=143.5 \mu\text{m}$, respectively.

For $\alpha=15 \mu\text{m}$ and another larger pitch difference of $\alpha=25 \mu\text{m}$, the elastic analysis is performed considering $C_{\min}=82 \mu\text{m}$ and $C_{\max}=143.5 \mu\text{m}$. The load condition is $F=30 \pm 11 \text{ kN}$. Fig. 13 shows the endurance limit diagrams for $\alpha=15 \mu\text{m}$ and $\alpha=25 \mu\text{m}$ considering the minimum and maximum clearances.

In Fig. 13 (a), when the clearance is changed from C_{\min} to C_{\max} for $\alpha=15 \mu\text{m}$, the stress status at root No. 8 changes slightly. In Fig. 13 (b), for $\alpha=25 \mu\text{m}$, with increasing the clearance from C_{\min} to C_{\max} , the mean stress decreases at roots No. 1 and No. 7 and the stress amplitude at root No. 8 increases slightly.

Fig. 14 and Fig. 15 show the contact status between bolt and nut for $\alpha=15 \mu\text{m}$ and $\alpha=25 \mu\text{m}$ considering the minimum and maximum clearance. The contacting threads are marked by the red arrows.

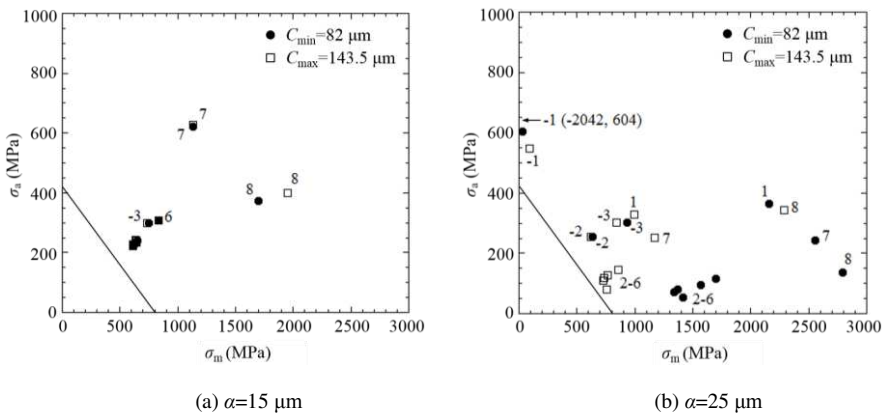


Figure 13

Endurance limit diagrams considering different clearance for $\alpha=15 \mu\text{m}$ and $\alpha=25 \mu\text{m}$

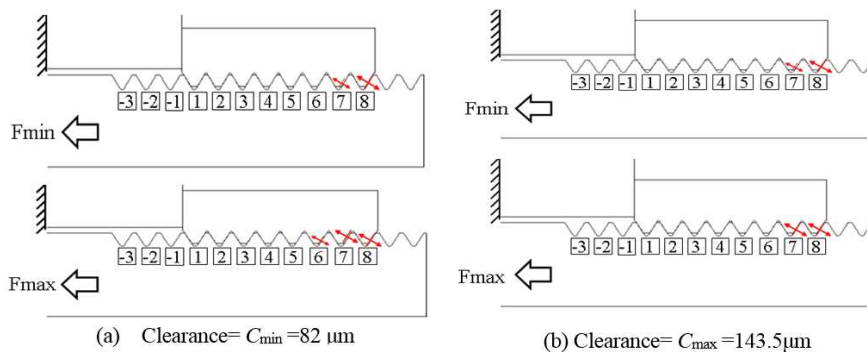


Figure 14
Contact status for $\alpha=15\ \mu\text{m}$

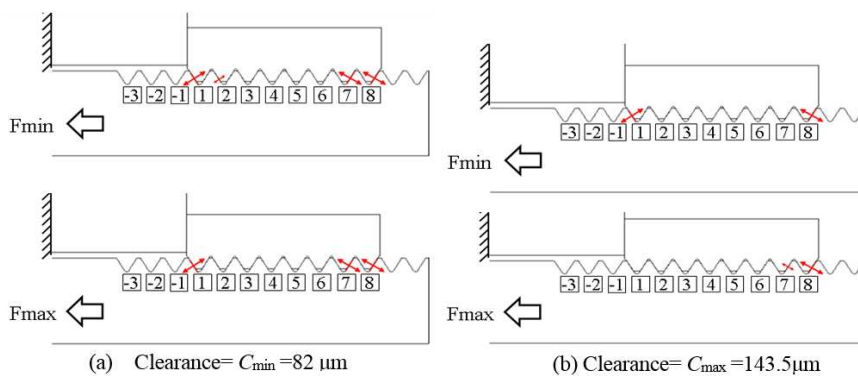


Figure 15
Contact status for $\alpha=25\ \mu\text{m}$

For $\alpha=15\ \mu\text{m}$ (Fig. 14), with increasing the clearance from C_{\min} to C_{\max} , the contact status between bolt and nut shows almost no difference under the same loads.

For $\alpha=25\ \mu\text{m}$ (Fig. 15), it can be seen that the contact status is quite different, when the clearance changed from C_{\min} to C_{\max} especially under the load F_{\max} . From the comparison between $\alpha=15\ \mu\text{m}$ and $\alpha=25\ \mu\text{m}$, it can be found that the clearance does not significantly affect the contact status for $\alpha=15\ \mu\text{m}$, but has a large affect for $\alpha=25\ \mu\text{m}$.

Conclusions

In this study, the fatigue fracture of bolt-nut connections having a slight pitch difference was considered, using experimental techniques and FEM analysis. The fatigue experiment was conducted for three specimens with different types of pitch differences. According to the FEM results, the stress states and the contact status at each root of bolt threads was presented and discussed. The conclusions can be summarized as follows:

- (1) For the standard bolt-nut connection ($\alpha=0\ \mu\text{m}$), the fatigue fracture happens at No. 1 thread, while it happens at No.-3 thread in Fig. 1 (b) for $\alpha=5\ \mu\text{m}$ and $\alpha=15\ \mu\text{m}$. The stress concentration at No.-3 thread can be reduced easily to avoid the fracture by changing No.-3 thread shape because of no contact of the nut. It is found that the fatigue life of bolt can be extended by introducing a suitable pitch difference, such as $\alpha=5\ \mu\text{m}$ and $\alpha=15\ \mu\text{m}$.
- (2) The FE analysis shows that both the stress amplitude and average stress at No. 1 bolt thread can be reduced by introducing a suitable pitch difference. For $\alpha=15\ \mu\text{m}$, instead of No. 1 thread, large stress appears at No. 7 and No. 8 threads although the fracture at No. 7 and No. 8 does not mean the final bolt fracture.
- (3) When the pitch difference is small, usually only No. 7 and No. 8 bolt threads contact with nut threads and the clearance changes. On the other hand, when the pitch difference is large, the contact status of No. 1 bolt thread may change from the left side contact in Fig. 1(b) to no contact. Therefore, with an increasing pitch difference, the clearance between bolt and nut significantly affects the contact status.

Acknowledgements

Mr. Ryuta Yosida and Mr. Huan Wang in the Mechanical Engineering Department, Kyushu Institute of Technology, are acknowledged for helping in the study. Partial financial support for this work from the Japanese Ministry of Education research expenses under grant no. 23560164 and Kitakyushu Foundation for the Advancement of Industry Science and Technology are appreciated.

The authors acknowledge the international collaboration grant funded by Commissie Wetenschappelijk Onderzoek (CWO), Faculty of Engineering and Architecture, Ghent University.

References

- [1] Bichford, J. H.: An Introduction to the Design and Behavior of Bolted Joints, 3rd edition, Marcel, Dekker, New York, America, 1995
- [2] Chaaban, A. and Jutras, M.: Static Analysis of Buttress Threads using the Finite Element Method. *Journal of Pressure Vessel Technology*, **114**, (1992) pp. 209-212
- [3] Chen, J. J. and Shin, Y. S.: A Study of the Helical Effect on the Thread Connection by Three Dimensional Finite Element Analysis. *Nuclear Engineering and Design*, **191** (1999) pp. 109-116
- [4] Grosse, I. R. and Mitchell, L. D.: Non-Linear Axial Stiffness Characteristic of Axisymmetric Bolted Joint. *ASME Transactions – Journal of Mechanical Design*, **112** (1990) pp. 442-449

- [5] Hard Lock Kogyo KK., Hard Lock Nut, Japanese Patent: 2002–195236, 2002 (In Japanese)
- [6] Hirai, K. and Uno, N.: Fatigue Strength of Super High Strength Bolt. *Journal of Structural Engineering*, **595** (2005) pp. 117-122
- [7] Hobbs, J. W., Burguete, R. L., Heyes, P. F. and Patterson, E. A.: The Effect of Eccentric Loading on the Fatigue Performance of High-Tensile Bolts. *International Journal of Fatigue*, **22** (2000) pp. 531-538
- [8] Izumi, S., Yokoyama, T. and Teraoka, T.: Verification of Anti-Loosening Performance of Super Slit Nut by Finite Element Method. *JSME – The Japan Society of Mechanical Engineers*, **71** (2005) pp. 380-386 (In Japanese)
- [9] Kawano, T., Kobayashi, Y., Harada, S. and Kuroshima, Y.: Fatigue Characteristics of Bolted Joints Tightened in Elastic and Plastic Region. *JSME – The Japan Society of Mechanical Engineers*, **1** (2001) pp. 233-234 (In Japanese)
- [10] Kenny, B. and Patterson, E. A.: Load and Stress Distribution in Screw Threads. *Experimental Mechanics*, **25** (1985) pp. 208-213
- [11] Kenny, B. and Patterson, E. A.: The Distribution of Load and Stress in the Threads of Fasteners. *Journal of Mechanical Behavior of Materials*, **2** (1989) pp. 87-105
- [12] Kuffova, M. and Necas, P.: Fracture Mechanics Prevention: Comprehensive Approach-based Modeling? *Acta Polytechnica Hungarica*, **7** (5) (2010) pp. 5-17
- [13] Majzoobi, G. H., Farrahi, G. H. and Habibi, N.: Experimental Evaluation of the Effect of Thread Pitch on Fatigue Life of Bolts. *International Journal of Fatigue*, **27** (2005) pp. 189-196
- [14] Maruyama, K.: Stress Analysis of a Bolt-Nut Joint by the Finite Element Method and the Copper-Electroplating Method. *JSME – The Japan Society of Mechanical Engineers*, **19** (1976) pp. 360-368 (In Japanese)
- [15] Nishida, S. I.: A Manufacturing Method of the Bolt Fastener, Japanese Patent: 2009-174564, 2009 (In Japanese)
- [16] Nishida, S. I.: A New Method for Fatigue Life Improvement of Screws. *European Structural Integrity Society*, **22** (1997) pp. 215-225
- [17] Nishida, S. I.: Failure Analysis in Engineering Applications. Butterworth-Heinemann, Oxford, UK, 1994
- [18] Nishida, S. I.: Screw Connection having Improved Fatigue Strength, United States Patent: 4,189,975, 1980
- [19] Noda, N. A., Xiao, Y., Kuhara, M., Saito, K., Nagawa, M., Yumoto, A. and Ogasawara, A.: Optimum Design of Thin Walled Tube on the Mechanical

- Performance of Super Lock Nut. *Journal of Solid Mechanics and Materials Engineering*, **2** (2008) pp. 780-791
- [20] Noda, N. A., Xiao, Y. and Kuhara, M.: The Reduction of Stress Concentration by Tapering Threads. *Journal of Solid Mechanics and Materials Engineering*, **5** (2011) pp. 397-408
- [21] Patterson, E. A. and Kenny, B.: A Modification to the Theory for the Load Distribution in Conventional Nuts and Bolts. *Journal of Strain Analysis for Engineering Design*, **21** (1986) pp. 17-23
- [22] Suzuki, H. and Kunio, T.: Influence of Yield-controlled and Angle-controlled Tightening Methods on Fatigue Strength of Bolted Joints. *Journal of the Society of Material Science*, **31** (1982) pp. 730-735 (In Japanese)
- [23] Xiao, Y., Kuhara, M., Noda, N. A., Saito, K., Nagawa, M. and Yumoto, A.: Optimum Dimensions of Thin Walled Tube on the Mechanical Performance of Super Stud Bolt. *JSME – The Japan Society of Mechanical Engineers*, **74** (2008) pp. 954-960 (In Japanese)
- [24] Yakushev, A. I.: Effect of Manufacturing Technology and Basic Thread Parameters on the Strength of Thread Connections. Pergamon press, Oxford, UK, 1964
- [25] Zhao, H.: Stress Concentration Factors within Bolt-Nut Connectors under Elasto-Plastic Deformation. *International Journal of Fatigue*, **20** (1998) pp. 651-659

Constituency Parse Reranking for Morphologically Rich Languages

Zsolt Szántó, Richárd Farkas

University of Szeged, Department of Informatics
Árpád tér 2, H-6700 Szeged, Hungary
szantozs@inf.u-szeged.hu, rfarkas@inf.u-szeged.hu

Abstract: In this article we introduce a constituent parsing system which can achieve state-of-the-art results on morphologically rich languages. Our system consists of a Probabilistic Context Free Grammars (PCFG) and n best reranking steps. We compare two methods to handle lexical sparsity in a PCFG parser. The n best reranking step, the discriminative reranker extracts large amount of features from n best parses of the PCFG parser and selects the best tree from these parses. We introduce three feature templates which extend the standard feature set of rerankers. We propose to extract features from Brown clustering – which is a context-based clustering over the words – and analyze the effect of dependency-based and morphology-based feature templates. The effects of these techniques are evaluated on datasets of eight morphologically rich languages.

Keywords: syntactic parsing; constituent parsing; morphologically rich languages; lexical sparsity; Brown clustering

1 Introduction

Syntax, in natural languages, describes the structure of a sentence and the grammatical relations between the words. In computational linguistics, syntactic parsing generally supports higher level tasks since the knowledge of the syntactic structure of a sentence can contribute to many natural language processing end-user applications like, machine translation and information retrieval. In this paper, we focus on constituent parsing, which is one of the most commonly used syntactic representations in computational linguistics (see Figure 1 for an example of constituent parse tree).

In the beginning, like many other fields of natural language processing, syntactic parsing systems focused on English. English is a strongly configurational language, while some morphologically rich languages (like Hungarian) exhibit free word order and express grammatical roles with morphology whereas in English, they are expressed by word order. Another difference between English

and morphologically rich languages is the number of word forms. Because of the inflectional nature of morphologically rich languages they contain many more word forms. The huge number of word forms is the reason for the lexical sparsity issue, which makes the parsing task more difficult. Here, we comparatively evaluate two methods targeting lexical sparsity.

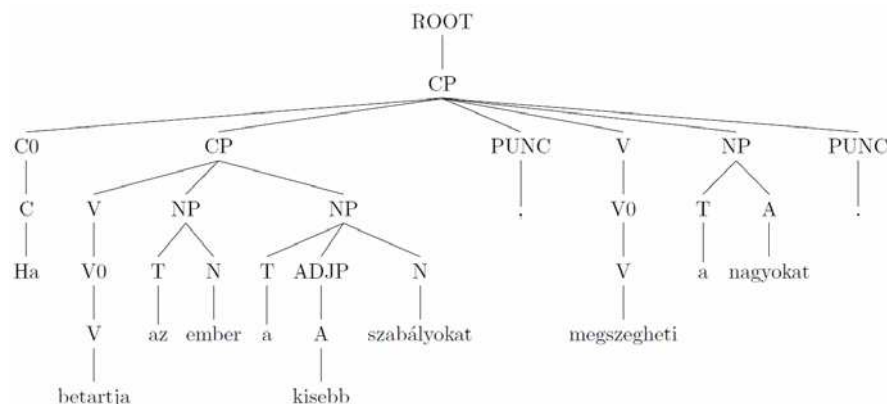


Figure 1

Constituency tree of a Hungarian sentence from Orwell’s 1984 (*‘If you kept the small rules, you could break the big ones.’*)

Constituent parsing systems usually use a discriminative n -best reranking step. These reranking systems can improve the performance of a first-stage PCFG parsing methods [20]. The first-stage parser must be fast so as to be able to select the best trees from all the possible parses, and the reranker can extract a rich feature set to describe the n best parses of the original parser and rerank the n candidate trees according to the features utilizing machine learning methods [6].

In this article we focus on this reranking step. On the Statistical Parsing of Morphologically Rich Languages (SPMRL) Shared Task datasets [22] – consisting of training and evaluation datasets for morphologically rich languages – we introduce and evaluate in detail three different feature sets which can improve the results in the case of these morphological rich languages. One of these feature sets directly focuses on the morphological rich data and exploits atomic morphological features, another applies information from dependency parsing, and the last one is based on Brown clusters. The latter method groups the words to hierarchical categories based on their context. This method also can help in the case of the out-of-vocabulary issue, which is the consequence of the large number of word forms.

The main contribution of this article is the introduction and the evaluation of these feature sets in the discriminative reranking step.

2 Related Work

Constituent parsing of English is a well researched area. The field has been dominated by data-driven, i.e. treebank-based statistical approaches in the last two decades [5, 6, 20]. We extend here the BerkeleyParser [20], which is a PCFG parser using latent annotations at non-terminals. Its basic idea is to iteratively split each non-terminal into subsymbols, thus capturing the different subusage of them instead of manually designed annotations. We use two different methods to handle the huge number of word forms. First, we create an extended lexicon [24] for the better estimation of tagging probabilities. Second, we use another method where we replace the rare words with their predicated POS tags [2]. Petrov [19] showed that the product of different grammars can improve the accuracy.

The most successful supervised constituent parsers contain a second feature-rich discriminative parsing step [6, 7, 14] as well. At the first stage they apply a PCFG to extract possible parses. The *n-best list rerankers* keep just the 50-100 best parses according to the PCFG [6]. These methods employ a large feature set (usually a few million features) describing parse candidates then use supervised machine learning techniques (learning-to-rank) to select the best parser based on the features [6, 10]. These feature sets are also engineered for English. To the best of our knowledge there is only one previous work which deals with the reranking of morphologically rich languages [12].

The constituent parsing of morphologically rich languages is a much less investigated field. There exist constituent treebanks for several languages along with a very limited number of parsing reports on them. For instance, [18] trained BerkeleyParser on Arabic, Bulgarian, French, German and Italian and he reported good accuracies, and there has been previous work on Hebrew [13], Korean [8] and Spanish [15] etc. The ‘Statistical Parsing of Morphologically Rich Languages’ [21] addressed the dependency and constituency parsing of morphologically rich languages and provides useful benchmark datasets for these languages.

Our chief contribution in this paper is the introduction of three feature sets for morphologically rich languages in the second stage reranking. Previously, the dependency based features were successfully applied to German [11]. Here, we experiment with them on seven morphologically rich languages. The morphological features [24] were designed especially for morphologically rich languages. To the best of our knowledge, the Brown clustering [4] based features have been previously not used in the context of reranking.

3 Experimental Setup

In our experiments we used the SPMRL 2014 Shared Task's data. It contains constituent and dependency trees on morphologically rich languages. This shared task also contains large unlabeled data sets in every language. We use seven languages from the shared task's data (Basque, French, German, Hebrew, Hungarian, Polish, and Swedish). Table 1 contains the basic statistics of the treebanks.

Table 1
Basic statistics of the treebanks used

	baq	fra	ger	heb	hun	pol	swe
#sent. in training	7577	14759	40472	5000	8146	6578	5000
#sent. in dev	948	1235	5000	500	1051	821	494
avg. token/sent.	12.93	30.13	17.51	25.34	21.75	10.15	15.59
#non-terminal labels	2764	693	709	507	676	675	137
#main POS labels	49	33	56	52	16	29	25
unk. token ratio (dev)	18.35	3.23	7.64	9.65	19.94	24.76	11.88

We use the PARSEVAL [1] score, which is the most common metric for the evaluation of constituent parsing. It is a standard F-score over labeled bracketings.

4 The Constituency System for Morphologically Rich Languages

The constituent parsing systems usually use two steps. The first step is a PCFG parser which selects the best parses from all possible trees relatively fast. In the first step we employed here the Berkeley Parser [20]. We introduce the second step in the Section 4.4.

4.1 Lexical Sparsity

Like many other parsers, the Berkeley Parser [20] was designed to English, but the huge number of wordforms create new challenges in the case of morphologically rich languages. We used two fundamentally different methods to handle the out-of-vocabulary issue. We built two standalone parsing systems based on these methods. One of these two techniques is the usage of extended lexicons [24]. We followed [13] and enhanced a lexicon model trained on the training set of the treebank with frequency information about the possible morphological analyses of tokens (*ExtendLex*). We estimated the tagging probability $P(t|w)$ of the tag t given the word w by

$$P(t | w) = \begin{cases} P_{tb}(t | w), & \text{if } c(w) \geq K \\ \frac{c(w)P_{tb}(t | w) + P_{ex}(t | w)}{1 + c(w)}, & \text{otherwise} \end{cases} \quad (1)$$

where $c(w)$ is the count of w in the training set, K is a predefined constant, $P_{tb}(t|w)$ is the probability estimate from the treebank (the relative frequency with smoothing) and $P_{ex}(t|w)$ is the probability estimate from an external lexicon. We calculated the emission probabilities $P(w|t)$ from the tagging probabilities $P(t|w)$ by applying the Bayesian rule. This method can exploit the available unlabeled data [24].

The other method is based on Clark and Curran's [9] work, where they replaced the rare words with their predicted POS tags in CCG grammars. We also used this strategy in our constituent parsing framework (*Replace*).

Both methods require automatically annotated POS tags. *Replace* uses these for replacing the rare words and *ExtendLex* for calculating new tagging probabilities. To get this information, we used MarMoT [17], which is a language independent POS-tagger. We trained MarMoT on the SPMRL's training sets. In some languages (Basque, French, German, Hungarian, Polish) we analyzed the word forms with the language-specific morphological analyzer and we used this information as features in MarMoT. Table 2 contains the accuracy of the part of speech tagging.

Table 2

POS and morphological feature accuracies of part of speech tagging on the development sets

	baq	fra	ger	heb	hun	pol	swe
MarMoT POS	97.52	97.08	97.98	96.97	98.49	98.39	97.40
MarMoT morph	87.81	89.36	90.38	97.15	97.45	91.00	97.16

4.2 Preterminal Set

The selection of the preterminal set in a PCFG is crucial and challenging in morphologically rich languages since they can consist of thousands of labels. To handle this issue, we have several options to use the morphological information at the preterminal level. First, we can use the full morphological descriptions (for example, $N##SubPOS=c|Num=s|Cas=n$ means that this is a common noun with nominative case in singular) or second, just the main part of speech tags (for example N). The full morphological description provides more information, but increases the data sparsity problem. The selection of the labels at the preterminal level is crucial to PCFG parsers, hence we can get very different results with different preterminal level [24].

Table 3
PARSEVAL scores on the development sets

	baq	fra	ger	heb	hun	pol	swe
Berkeley mainPOS	72.32	79.35	82.26	88.71	83.84	86.75	75.19
Berkeley fullMorph	77.82	79.17	80.22	88.40	87.18	85.06	72.82

Table 3 contains the results of the Berkeley Parser with main POS and full morphological description. We can see that in Basque and Hungarian the usage of full morphological description obtains higher results, but in the other languages we can get better results with main POS. Our two methods used the POS tags differently. In the case of *ExtendLex* we used the full morphological description at the preterminal level. In the case of *Replace* the preterminal level always contained the main POS tags.

4.3 Product Parser

The Berkeley Parser uses an iterative expectation–maximization approach to calculate the latent variables [20]. This is a local search algorithm and the result of this optimization is highly dependent on the initialization of the variables. In every iteration the Berkeley Parser splits the latent variables in two with a small amount of randomness. Petrov showed [19] that the modification of these random values can change the result of the parsing. We can get different parsers when we only change the random seed. If we product the probabilities of the same sentence with these different grammars, we can get better scores than in the case when we just used one grammar. Based on this experience, we trained 8 grammars with different random seeds and we obtained the product of them.

4.4 Reranker for Morphologically Rich Languages

The second step of our constituency pipeline is discriminative reranking. We conducted ranking experiments on the 50-best outputs of the product grammars. We used a slightly modified version of the Mallet toolkit [16], where the reranker was trained for the maximum entropy objective function of Charniak and Johnson [6] and used the standard feature set from Charniak and Johnson [6] and Collins [10]. We propose here new feature templates exploiting automatic dependency parses of the sentence in question; Brown clusters; and atomic morphological feature values. Our purpose here is to investigate the efficiency of these feature templates in morphologically rich languages. For these studies we used the product grammar configuration. Here, we present our feature templates in more detail.

4.4.1 Morphology-based Features

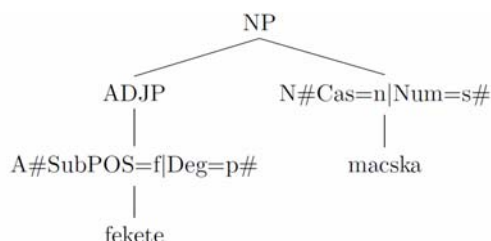


Figure 2

Constituency tree of a Hungarian noun phrase (*black cat*)

We created features from the full morphological description by using each morphological feature separately [24]. This approach allows us to combine a word with its morphological features, for example the word *macska*, which is a noun in nominative case, we made the (macska-N-Cas=n) feature (see Figure 2).

We also made features from the phrases, where we used the combination of a phrase and their head's morphological features. In our example we can create two features from the *NP*: NP-N-Cas=n and NP-N-Num=s.

If the phrase contains other children, we can create more features from these parent-daughter relations. The new features contain the morphological features of the head of the parent and the head of the daughter. In the *fekete macska* example we can get 4 features: NP-Cas=n-ADJP-SubPOS=f, NP-Cas=n-ADJP-Deg=p, NP-Num=s-ADJP-SubPOS=f, NP-Num=s-ADJP-Deg=p.

New features are established using constituency labels and morphological features of the phrase's head, as well as morphological features of the head and its dependent. To find the heads we only use the main POS tags in the case of the *Replace* method, these new features could only be applicable to *ExtendLex*. Here we used simple methods to find the heads of the nonterminals, but we could probably improve the results with more refined head finding rules.

4.4.2 Dependency-based Features

The SPMRL 2014 Shared Task had a dependency track. The organizers provided dependency annotations over the same texts. We used our team's dependency prediction [3] and created features from that. These features are made from heads of constituents and their dependency relations. We used features describing relations between the same head-dependent pairs in both the constituency and dependency parses. The features are described in detail in [11]. The frequency of these relations was also used.

These features are especially interesting for Hungarian because we have two manually annotated corpora in both representations as opposed to the other SPMRL languages [23].

4.4.3 Brown Cluster-based Features

We defined Brown cluster-based features. Brown clustering is a context-based hierarchical clustering over words [4]. Brown clusters are useful for syntax because words with similar context may have similar grammatical roles. These features can handle the feature sparsity issue. Utilizing these clusters, we duplicated every feature containing word by replacing each of those words with their Brown clusterID.

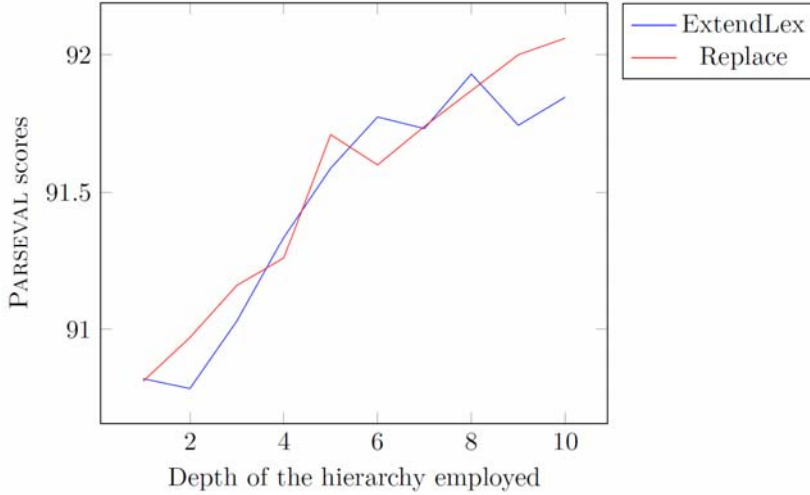


Figure 3

Results of Brown cluster based feature templates on the Hungarian dataset

Figure 3 investigates the effect of employing different levels of the Brown hierarchical tree evaluated on the Hungarian dataset. We obtained similar improvement in the case of both methods, *Replace* and *ExtendLex*, namely that these features increased the PARSEVAL metric with ~ 0.9 percentage point. We optimized the depth of hierarchy for each language separately.

5 Results and Discussion

As our baselines we used the results from Table 3. It contains the result of the Berkeley Parser with main POS and full morphological lexicon.

Table 4 shows the results achieved by the two strategies for handling lexical sparsity and the effect of the usage of the product of different grammars. The *Baseline* row contains the best results from Table 3. The product of the grammars increased the accuracy in every case. We obtained the best results with the

Replace Product system in six languages, but this strategy could not predict the full morphological description. In the case of French the *ExtendLex Product* obtained slightly better scores. In the next step we added the reranker stage to our product parsing systems.

Table 4
PARSEVAL scores on the development sets for the predicted setting

	baq	fra	ger	heb	hun	pol	swe
Baseline	77.82	79.35	82.26	88.71	87.18	86.75	75.19
ExtendLex	77.57	79.67	81.54	88.24	88.99	88.21	74.52
Replace	84.27	80.26	82.99	89.73	89.59	90.29	77.08
ExtendLex Product	79.47	81.38	82.94	89.22	90.43	91.52	78.21
Replace Product	85.31	81.29	84.55	89.87	90.72	92.28	78.66

Table 5 shows the final results of the reranker on the development set. We evaluated the effect of each new feature template and the combinations of all feature sets. *dflt* is the standard feature set from Charniak and Johnson [6] and Collins [10]. We added our morphology-based (*morph*), dependency-based (*dep*) and Brown cluster-based (*Brown*) features to this baseline. In the case of configurations, which contain Brown cluster based features, we show the best results in Table 5.

Table 5
PARSEVAL scores of the reranker on the development set for the predicted setting

ExtendLex	baq	fra	ger	heb	hun	pol	swe
Reranked <i>dflt</i>	79.16	81.92	83.01	89.39	91.06	87.89	79.09
Reranked <i>dflt+morph</i>	79.41	82.88	83.36	89.63	91.27	88.31	77.96
Reranked <i>dflt+dep</i>	81.89	82.65	84.83	90.28	91.88	91.84	79.43
Reranked <i>dflt+Brown</i>	80.63	82.49	84.33	90.30	91.93	89.37	78.42
Reranked <i>dflt+morph+dep+Brown</i>	82.69	82.62	85.16	90.64	92.05	91.10	79.57
Replace							
Reranked <i>dflt</i>	86.11	82.30	84.59	90.02	91.09	88.31	78.87
Reranked <i>dflt+dep</i>	86.73	82.78	86.05	90.47	91.89	90.53	79.38
Reranked <i>dflt+brown</i>	86.57	82.65	85.85	90.62	92.06	92.24	80.16
Reranked <i>dflt+dep+brown</i>	87.24	82.94	86.56	90.73	92.40	92.41	80.71

Reranking with default features improved the scores over product grammars both for *ExtendLex* and *Replace*. In the case of both representations, the combination of the proposed feature templates further increased our scores except for Swedish, where the morphology-based features and Brown cluster-based features also decreased the accuracy of the *ExtendLex* method, but when we added each new feature set, we obtained a slight improvement compared to the *dflt+dep* model. Finally, the *Replace* method obtained higher scores in every language. But in some languages (French, Hebrew, Hungarian) the difference is small and we can keep the morphological information with *ExtendLex*. We plan to combine these two fundamentally different methods in the future.

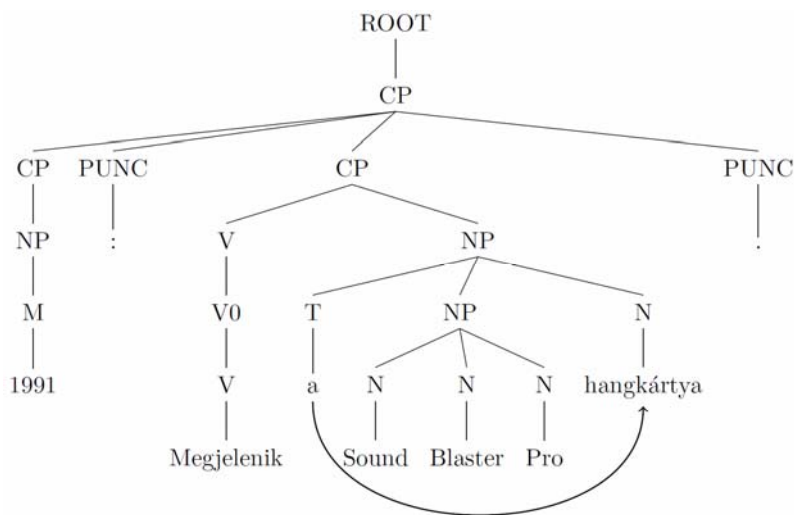


Figure 4

The gold standard parse of a Hungarian sentence with a dependency edge (*1991: The Sound Blaster Pro soundcard has appeared*)

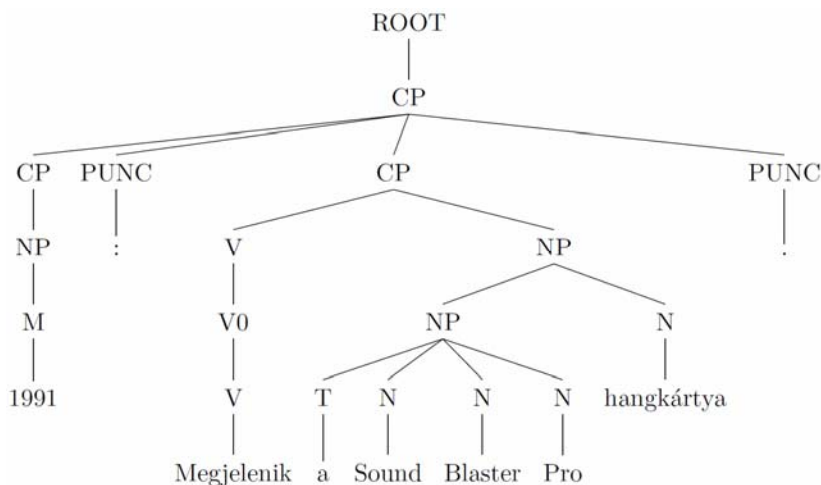


Figure 5

The reranked parse of a Hungarian sentence without dependency-based features

We manually analyzed the effect of new feature sets. Figures 4 and 5 show an example for the usefulness of the dependency based features. Figure 4 contains the correct parse of a Hungarian sentence. Figure 5 contains the result of our constituent parsing system to this sentence where we used the baseline (*dflt*) configuration. With dependency-based features (*dep*) we obtained the correct

parse. There is only one difference between the two parses. In the correct parse the article is connected to the noun phrase of "*Sound Blaster Pro hangkártya*" and in the wrong parse this article is connected to the noun phrase of "*Sound Blaster Pro*". If the computer does not see the dependency parse of this sentence, then the second parse is likely a good choice because a noun follows the article. But in the dependency parse there is a relation from the article to the noun *hangkártya*, and the dependency-based features encode this relationship, so the correct parse can be yielded.

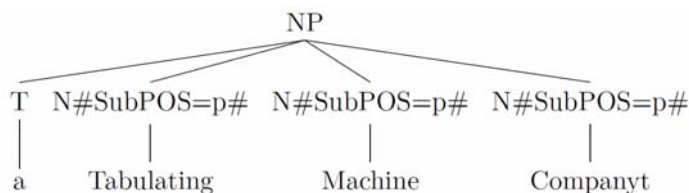


Figure 6

The gold standard parse of a part of a Hungarian sentence (the Tabulating Machine Company in accusative)

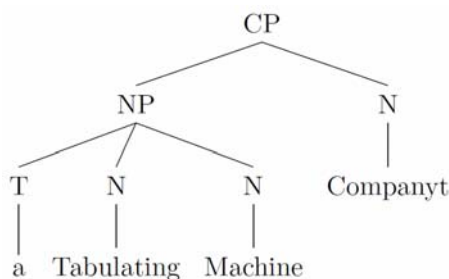


Figure 7

The reranked parse of a part of a Hungarian sentence without morphology-based features

Figure 6 and Figure 7 contain the parse of a part of a Hungarian sentence. In this phrase, "*Tabulating Machine Companyt*" is a proper noun, where "*Companyt*" is in the accusative case and the "a" is the article of the proper noun. In Hungarian a noun phrase can consist of the parts of a multi-word proper noun, like in Figure 6. Our parser (without morphology-based features) splits the expression because the parser has insufficient information to decide whether it is a multi-word proper noun, or it is just a sequence of independent nouns. In this expression, all wordforms are very rare. Instead of the usage of the wordforms, when we employ the morphology-based features, we can use binary features that encode whether the head of the NP (*Companyt*) is a proper noun and the head of the NP also has a sibling, which is a proper noun. Hence, these features can increase the probability of the correct sentence.

In the case of Brown-cluster based features we evaluated the F-score of the non-terminal labels. We found improvement in the case of labels ADJP (2.88), CP (1.39) and NP (0.86). The Brown clusters can group syntactically similar words, for instance, it clusterized the superlative adjectives and the ordinal numerals to one cluster. These words behave similarly at the syntax level since both groups usually function as the head of an ADJP. These automatically found similarities can help the reranker to choose the best parse from the candidates.

Conclusions

In this paper we introduced a system which achieved state-of-the-art results in constituent parsing of morphologically rich languages. We improved the efficiency of the discriminative reranking step with new feature templates. We proposed novel features from Brown clustering of the words and analysed the effect of morphology-based, dependency-based and Brown cluster-based features. The *Replace* method obtain better results for each of the languages, because this method can handle the lexical sparsity and also can handle the preterminal sparsity. The Brown cluster-based and the dependency-based features considerably contributed the system's performance and their beneficial effects overlap only to a small extent.

References

- [1] S. Abney, S. Flickenger, C. Gdaniec, C. Grishman, P. Harrison, D. Hindle, R. Ingria, F. Jelinek, J. Klavans, M. Liberman, M. Marcus, S. Roukos, B. Santorini and T. Strzalkowski. Procedure for Quantitatively Comparing the Syntactic Coverage of English Grammars. In E. Black, editor, *Proceedings of the workshop on Speech and Natural Language*, pp. 306-311, 1991
- [2] Anders Björkelund, Özlem Çetinoğlu, Richárd Farkas, Thomas Müller and Wolfgang Seeker. (Re)ranking Meets Morphosyntax: State-of-the-art Results from the SPMRL 2013 Shared Task. In *Proceedings of the Fourth Workshop on Statistical Parsing of Morphologically-Rich Languages*, pp. 135-145, October 2013
- [3] Anders Björkelund, Özlem Çetinoğlu, Agnieszka Faleńska, Richárd Farkas, Thomas Müller, Wolfgang Seeker, and Zsolt Szántó. Introducing the IMS-Wroclaw-Szeged-CIS entry at the SPMRL 2014 Shared Task: Reranking and Morpho-syntax meet Unlabeled Data. In *Proceedings of the First Joint Workshop on Statistical Parsing of Morphologically Rich Languages and Syntactic Analysis of Non-Canonical Languages*, pp. 97-102, August 2014
- [4] Peter F. Brown, Vincent J. Della Pietra, Peter V. deSouza, Jenifer C. Lai, and Robert L. Mercer. Class-based n-gram Models of Natural Language. *Computational Linguistics*, 18(4):467-479, 1992

- [5] Eugene Charniak. A Maximum-Entropy-inspired Parser. In Proceedings of the 1st North American chapter of the Association for Computational Linguistics conference, pp. 132-139, 2000
- [6] Eugene Charniak and Mark Johnson. Coarse-to-Fine n-Best Parsing and MaxEnt Discriminative Reranking. In Proceedings of the 43rd Annual Meeting on Association for Computational Linguistics, ACL '05, pp. 173-180, 2005
- [7] Xiao Chen and Chunyu Kit. Higher-Order Constituent Parsing and Parser Combination. In Proceedings of the 50th Annual Meeting of the Association for Computational Linguistics (Volume 2: Short Papers) pp. 1-5, 2012
- [8] Key-Sun Choi, Young S Han, Young G Han, and Oh W Kwon. KAIST Tree Bank Project for Korean: Present and Future Development. In Proceedings of the International Workshop on Sharable Natural Language Resources, pp. 7-14, Citeseer, 1994
- [9] Stephen Clark and James R. Curran. Wide-Coverage Efficient Statistical Parsing with CCG and Log-Linear Models. Computational Linguistics, 33, 2007
- [10] Michael Collins. Discriminative Reranking for Natural Language Parsing. In Proceedings of the Seventeenth International Conference on Machine Learning, ICML '00, pp. 175-182, 2000
- [11] Richárd Farkas, Bernd Bohnet and Helmut Schmid. Features for phrase-structure reranking from dependency parses. In Proceedings of the 12th International Conference on Parsing Technologies, pp. 209-214, 2011
- [12] Alexander Fraser, Helmut Schmid, Richárd Farkas, Renjing Wang and Hinrich Schütze. Knowledge Sources for Constituent Parsing of German, a Morphologically Rich and Less-Configurational Language. Comput. Linguist., 39(1):57-85, March 2013
- [13] Yoav Goldberg and Michael Elhadad. Word Segmentation, Unknown-Word Resolution, and Morphological Agreement in a Hebrew Parsing System. Computational Linguistics, 39(1):121-160, 2013
- [14] Liang Huang. Forest Reranking: Discriminative Parsing with Non-Local Features. In Proceedings of ACL-08: HLT, pp. 586-594, 2008
- [15] Joseph Le Roux, Benoit Sagot and Djamé Seddah. Statistical Parsing of Spanish and Data Driven Lemmatization. In Proceedings of the ACL 2012 Joint Workshop on Statistical Parsing and Semantic Processing of Morphologically Rich Languages, pp. 55-61, 2012
- [16] Andrew Kachites McCallum. "Mallet: A Machine Learning for Language Toolkit". <http://mallet.cs.umass.edu>, 2002
- [17] Thomas Mueller, Helmut Schmid and Hinrich Schütze. Efficient Higher-Order CRFs for Morphological Tagging. In Proceedings of the 2013

- Conference on Empirical Methods in Natural Language Processing, pp. 322-332, 2013
- [18] Slav Petrov. Coarse-to-Fine Natural Language Processing. PhD thesis, University of California at Berkeley, Berkeley, CA, USA, 2009
- [19] Slav Petrov. Products of Random Latent Variable Grammars. In *Human Language Technologies: The 2010 Annual Conference of the North American Chapter of the Association for Computational Linguistics*, pp. 19-27, Association for Computational Linguistics, 2010
- [20] Slav Petrov, Leon Barrett, Romain Thibaux and Dan Klein. Learning Accurate, Compact, and Interpretable Tree Annotation. In *Proceedings of the 21st International Conference on Computational Linguistics and 44th Annual Meeting of the Association for Computational Linguistics*, pp. 433-440, 2006
- [21] Djamé Seddah, Sandra Kübler and Reut Tsarfaty. Introducing the SPMRL 2014 Shared Task on Parsing Morphologically-Rich Languages. In *Proceedings of the First Joint Workshop on Statistical Parsing of Morphologically Rich Languages and Syntactic Analysis of Non-Canonical Languages*, pp. 103-109, 2014
- [22] Djamé Seddah, Reut Tsarfaty, Sandra Kübler, Marie Candito, Jinho Choi, Richárd Farkas, Jennifer Foster, Iakes Goenaga, Koldo Gojenola, Yoav Goldberg, Spence Green, Nizar Habash, Marco Kuhlmann, Wolfgang Maier, Joakim Nivre, Adam Przepiorkowski, Ryan Roth, Wolfgang Seeker, Yannick Versley, Veronika Vincze, Marcin Woliński and Alina Wróblewska. Overview of the SPMRL 2013 Shared Task: A Cross-Framework Evaluation of Parsing Morphologically Rich Languages. In *Proceedings of the 4th Workshop on Statistical Parsing of Morphologically Rich Languages: Shared Task*, Seattle, WA, 2013
- [23] Katalin Iлона Simkó, Veronika Vincze, Zsolt Szántó and Richárd Farkas. An Empirical Evaluation of Automatic Conversion from Constituency to Dependency in Hungarian. In *Proceedings of COLING 2014, the 25th International Conference on Computational Linguistics: Technical Papers*, pp. 1392-1401, Dublin City University and Association for Computational Linguistics, 2014
- [24] Zsolt Szántó and Richárd Farkas. Special Techniques for Constituent Parsing of Morphologically Rich Languages. In *Proceedings of the 14th Conference of the European Chapter of the Association for Computational Linguistics*, pp. 135-144, Gothenburg, Sweden, April 2014

Models for Force Control in Telesurgical Robot Systems

**Árpád Takács¹, Levente Kovács², Imre J. Rudas¹,
Radu-Emil Precup³, Tamás Haidegger^{1,4}**

¹ Óbuda University, Antal Bejczy Center for Intelligent Robotics, Kiscelli u. 82,
H-1032 Budapest, Hungary

² Óbuda University, Physiological Controls Group, Bécsi út 96/b, H-1034
Budapest, Hungary

³ Politehnica University of Timisoara, Department of Automation and Applied
Informatics, Bd. V. Parvan 2, RO-300223 Timișoara, Romania

⁴ Austrian Center For Medical Innovation and Technology,
Viktor-Kaplan-Straße 2, A-2700 Wiener Neustadt, Austria

{arpad.takacs, imre.rudas, tamas.haidegger}@irob.uni-obuda.hu,
kovacs.levente@nik.uni-obuda.hu, radu.precup@upt.ro

Abstract: Surgical robotics is one of the most rapidly developing fields within robotics. Besides general motion control issues, control engineers often find it challenging to design robotic telesurgery systems, as these have to deal with complex environmental constraints. The unique behavior of soft tissues requires special approaches in both robot control and system modeling in the case of robotic tissue manipulation. Precise control depends on the appropriate modeling of the interaction between the manipulated tissues and the instruments held by the robotic arm, frequently referred to as the tool–tissue interaction. Due to the nature of the physiological environment, the mechatronics of the systems and the time delays, it is difficult to introduce a universal model or a general modeling approach. This paper gives an overview of the emerging problems in the design and modeling of telesurgical systems, analyzing each component, and introducing the most widely employed models. The arising control problems are reviewed in the frames of master–slave type teleoperation, proposing a novel soft tissue model and providing an overview of the possible control approaches.

Keywords: surgical robotics; force control; tissue modeling; teleoperation; time delay control

1 Introduction

Healthcare services that are performed or supported by robots from long distances have opened new frontiers in diagnosis and surgery. The initial idea of teleoperation first appeared at NASA in the early 1970s [1]) The idea telesurgery was born in the concept of space exploration. Although the concept of telesurgery in space has never been implemented in real applications, several simulations and research projects have led the development to breakthrough in 2001, when the first intercontinental telesurgical procedure was carried out between the USA and France, based on ISDN communication [2]) The successful procedure proved that theoretically, in special, urgent cases, doctors and surgeon could contact and reach out for patients thousands of kilometers away.

It is most likely that in the near-future, the research and development of telesurgical applications will focus on applications in remote, rural and dangerous areas such as war zones or contaminated sectors. It is evident that the difference between surgical procedures on Earth and in space environments is vast, in terms of complexity. During the past decade, several remote surgery experiments were conducted by NASA on Earth, under extreme conditions. The experiments took place in the world's only permanent undersea laboratory, NEEMO (NASA Extreme Environment Mission Operations), concluding their latest project on September 13, 2014.

Existing issues in telesurgery include the modeling and control challenges of both master and slave sides, while the communication with the surgical crew on Earth creates further issues to address. Most of the difficulties in teleoperation are caused by signal latency and lagging. With the increase of the distance between the master and slave sides, these effects are magnified. Many disturbing effects can be reduced in a general teleoperation surgical robotic system by a well-chosen system architecture and proper control methods. A detailed review article about the current capabilities in surgical robotics, primarily focusing on teleoperated systems was published by Hoeckelmann et al. [4], while available options and a proposed control and modeling framework for telesurgical applications was proposed by Jordán et al. in [5].

One of the major issues of currently available telesurgical systems is the lack of reliable haptic feedback, leaving surgeons to only rely on their visual sensing during procedures. The aim of this work is to give an overview of the concept of telesurgery, approaching the problem from the modeling point of view, addressing the effect of force control and the role of modeling. In Section 2, a state of the art overview is given about telesurgery today, Section 3 briefly presents the components of a telesurgical system, addressing some issues and modeling approaches. Section 4 describes the problem of tool–tissue interaction, giving a thorough summary of the most relevant models found in the literature, with special attention to the available soft tissue models and approaches.

2 State of the Art

Today, the da Vinci Surgical System by Intuitive Surgical Inc. (Sunnyvale, CA) is the best-known and most popular surgical robot system, functioning as a teleoperated manipulator. As of March 31, 2015, there was an installed base of 3,317 units worldwide: 2,254 in the United States, 556 in Europe, 194 in Japan, and 313 in the rest of the world [6]. In the case of the da Vinci, the system is not used routinely for long-distance procedures and interventions. Primarily due to the limitations of the communication protocol, which is a custom-developed component of the system. However, there is a potential for using the da Vinci robot at a greater distance, which has been proved by some limited experiments. One of these includes the collaborative telerobotic surgery initiation by DARPA in 2005, when several modified da Vinci consoles were able to overtake the control from one another through the Internet [7]. In 2008, CSTAR (Canadian Surgical Technologies and Advances Robotics, London, ON) used the core network of Bell Canada for testing a modified, telesurgery-enabled version of the da Vinci. Altogether six successful pyeloplasty procedures were performed on porcine kidneys using telesurgery, with the slave manipulator located in Halifax, Nova Scotia, 1,700 kilometers away from the controllers [8]. The Plugfest was one of the most notable experiments in the past years in this research domain, allowing eight master devices to connect with six slave machines [9]. Simulated interventions such as peg transfer tasks (SAGES Fundamentals of Laparoscopic Surgery) were successfully supported for more than 24 hours, using the Interoperable Teleoperation Protocol (ITP) [10]. The recent advances in the reliability of the Internet network allows these high-level experiments to be executed safely, however, the Internet backbone infrastructure is becoming overloaded, with an immediate effect on the lag times [11]. In order to protect the patients in the future, some of the security issues need to be addressed, in accordance with IEC 80001-1:2010. When we discuss control over delayed channel, numerous safety and performance issues arise. Furthermore, there is a need for surgical training in the use of latency-affected master console, helping the operators learn how to tolerate latencies and other disturbing effects [12].

3 Teleoperation Systems

Just like every teleoperation system, master–slave surgical robots systems in general consist of three major components from the control and modeling point of view: the slave device, the master device and the communication system. In the field of telesurgery, slave-side modeling is extended with the phenomena of tool–tissue interaction, the contact problem addressing the behavior of the tool and the soft/hard tissue under manipulation. The modeling of the components is essential

for building a valid simulator for the system as a whole, creating the possibility of observation and analysis of control attributes, properties and behaviors. The models are subject to validation, both individually and as a part of the assembly. The schematic illustration of the functional components of a general telesurgical system is shown in Fig. 1.



Figure 1

Block diagram of a general telesurgical system from the control point of view

3.1 Communication System

The communication system is the component responsible for data transfer, coding and decoding control signals and other tasks that make the communication between the master and slave devices possible at all levels. In general, the communication system includes a transmitter, a receiver and the communication medium. Signal quality and latency are both dependent from the subcomponents, individually. Besides quality issues, in telesurgical systems data loss is one of the most critical problems to be solved, which is, in general, the best handled by particular custom-designed protocols or the User Datagram Protocol (UDP) [11].

Humans have limited adaptability to time delay, it generally varies between 0.3–0.5 seconds. In 2001, during the first trans-Atlantic telesurgical intervention, the Zeus robot was in use, created by Computer Motion (Mountain View, CA) was recording a mean signal delay of 155 ms [14]. According to the measurements, 85 ms of lag appeared in signal transmission, while it took 70 ms to encode and decode the video streaming from the slave side. It is important to note that currently all surgical robots employed routinely in clinical applications are only providing visual and audio feedback. Haptic feedback is yet to be perfected due to stability issues. Data encoding would also increase the lag in long-distance communication.

Effects of time delay can be reduced with various control methods designed for latency-tolerance, therefore, there is an opportunity to bridge larger distances with these technologies. In order to achieve this, the system components must be modeled in a robust way, including all three main components of the teleoperation system. From the communication system approach, the master includes a controller and/or a human operator, subject to latencies, which is interconnected with the slave model through a high-delay medium. Using appropriate predictive controllers, the time delay can be partially alleviated in the deriving cascade setup, if the controller is well-tuned for both the master and slave systems [15].

3.2 Master Model

The master side is the component, where the human operator or a control device is located. In the past decades, several human models have been created to address the human behavior in the control loop. One of the most significant classical models is the crossover model, which was developed in the 1960s in order to model the behavior of fighter pilots during flight [16]. The crossover model is based on the time-dependent non-linear response of the human body, using a quasi-linear approximation. The complexity of the model highly depends on the precision of the task to be executed. However, there is a commonly used, reasonably good approximation:

$$H(s) = K_p \frac{\tau_L s + 1}{\tau_I s + 1} \left(\frac{e^{-\tau s}}{\tau_N s + 1} \right), \quad (1)$$

where the term in the brackets stands for the human physiological limitations, including the delay of the human reaction time. The time constant τ_N refers to the neuromuscular system, where the delay occurs. K_p represents a static gain, while τ_I and τ_L express the time delay section and the control time constant, respectively. The trade-off for the simplicity of this model is that it does not represent other, detailed human attributes such as motivation, expertise and fatigue.

Another popular model of human operators was created by Ornstein [17]. A significant development compared to the crossover model is that the Ornstein model can also be applied in tracking tasks:

$$H(s) = \frac{a_1 s + a_0}{b_2 s^2 + b_1 s + b_0} e^{-\tau s}. \quad (2)$$

The coefficient values are determined by taking some physical attributes into account, such as velocity or static gain [18]. Due to the relatively high number of parameters, this model can become rather sophisticated, allowing one to describe neuromuscular effects or other dynamic response characteristics [19]. Furthermore, a large variety of sensory input noise can be modeled using a general signal disturbance, creating the possibility to include vision modeling [20].

In practice, the most commonly used non-linear human operator model is the GM/UMTRI car driver representation, developed at General Motors. The basis of this model is a general, quasi-linear UMTRI driver model [21]. These models have been widely used for the representation of master-slave type telesurgical tasks [22].

3.3 Slave Side Models

In telesurgical applications, functionality and safety requirements are, in general, higher than in other robotic applications. At the design stage, autonomous capabilities and proper mechanical modeling are important in satisfying these issues. In general, the kinematic model of a slave robot is described at a high level of precision in the details, enabling its integration in dynamic and kinematic models [23], [24]. These models, along with the appropriate image guidance and modeling, can largely increase the accuracy and safety of surgical interventions [25].

In robotic surgery, one of the most critical issues is the correct description of the model of the robot arm, the model of the manipulated tissue, and the behavior of these elements during manipulation tasks, on contact. This paper primarily focuses on soft tissue manipulation problems, while the issues involving hard tissues are in the focus of machining technology studies since drilling, milling and turning are exposed to great vibration and thus require stability issues. Most of the types of human soft tissues are inhomogeneous, viscoelastic, anisotropic and highly non-linear materials. Therefore, object grabbing, cutting and other deformation analyses require significant effect.

3.4 Soft Tissue Models

Minimal Invasive Surgical (MIS) applications require an effective surgical training of the medical crew, which, in general, is achieved by virtual surgical training. Famaey and Sloten created a comprehensive review of the existing and most widely used soft tissue models that are integrated in MIS virtual surgical interfaces, introducing three major categories of tissue deformation and stress models [26]:

- Heuristic models (mass–spring–damper models)
- Continuum-mechanics based models
- Hybrid models

It is important to note that the complexity of the models within these categories varies on a wide scale, therefore, it is hard to compare them to each other. Due to their common use in finite element modeling, continuum-mechanics based models are considered to be the best approach for modeling realistic response to the task. In practice, continuum-mechanics based models require high computational capacity, whereas analytical solutions usually do not exist. The global behavior of soft tissues, particularly their viscoelastic nature can be modeled in a simpler way by using heuristic models. These consist of virtual mass, spring and damper elements, lumped together, ideal for describing simple manipulation tasks, such as grabbing, one-dimensional indentation or needle insertion. Due to the simplicity of

this approach, analytical or semi-analytical solutions usually exist. The most commonly used heuristic models are shown in Fig. 2.

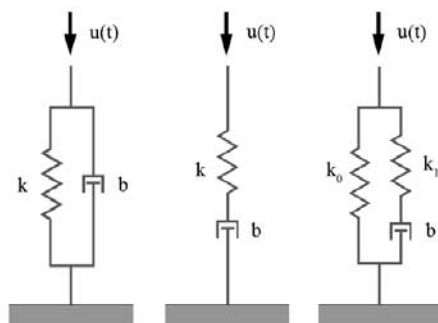


Figure 2

The most commonly used mechanical models of viscoelasticity:

a) Voigt model, b) Maxwell model, c) Kelvin model

Spring and damper elements combined provide a versatile tool for viscoelastic behavior description. In small scales, when the strain according to the applied force remains under 1%, the use of purely linear, single-spring element models is justified. However, in practice, the complex geometry and the highly nonlinear behavior of soft tissues require advanced models. The modularity and the possibility of analytical solutions provide a great advantage by using heuristic soft tissue models. A detailed overview of the mass–spring–damper models have been presented in [28]. It was also shown that based on experimental data these models can provide realistic response for 1-DoF (Degree of Freedom) indentation tasks in the tissue relaxation phase, e.g. when the tissue is compressed at a high speed with a step-like input and is kept at that deformation until the transient force response settles down.

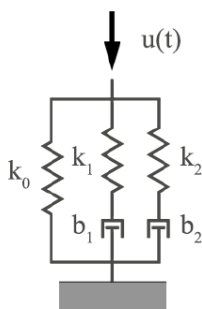


Figure 3

The proposed heuristic soft tissue model, the nonlinear Wiechert model

The nonlinear model shown in Fig. 3 was used in [29] for the verification of liver indentation experiments, showing that an 8-parameter mass–spring–damper model can be used for the estimation of force response under 1-DoF indentation of soft tissues. The model is built up from a nonlinear spring element in a parallel connection with 2 nonlinear Maxwell-bodies, where the spring stiffness characteristics are represented by:

$$k_i(x) = K_i e^{\kappa_i x}, \quad (3)$$

where x denotes the compression size of the spring elements, K_i and κ_i , $i = 1, 2, 3$ denote the spring characteristics constants, while $b_{1,2}$ are linear damping elements. If x_0 refers to a point on the soft tissue surface, x_1 and x_2 mark the position of two virtual points inside the Maxwell-bodies, the proposed nonlinear soft tissue model can be written in the following state–space form:

$$\begin{aligned} \dot{x}_0 &= u(t) \\ \dot{x}_1 &= \frac{1}{b_1} K_1 (x_0 - x_1) e^{\kappa_1 (x_0 - x_1)} \\ \dot{x}_2 &= \frac{1}{b_2} K_2 (x_0 - x_2) e^{\kappa_2 (x_0 - x_2)}, \end{aligned} \quad (4)$$

where $u(t)$ is the system input, representing the surface deformation velocity profile, while the system output, $y(t)$ stands for the force response of the system, i.e. the reaction force at the soft tissue surface:

$$y(t) = K_0 x_0 e^{\kappa_0 x_0} + K_1 (x_0 - x_1) e^{\kappa_1 (x_0 - x_1)} + K_2 (x_0 - x_2) e^{\kappa_2 (x_0 - x_2)}. \quad (5)$$

4 Tool–Tissue Interaction Models

In the past years, the topic of tool–tissue interaction modeling has gained interest due to the elevated demand for teleoperation and telemanipulation, as well for sophisticated control methods for advanced manipulators, which also require precise path planning for autonomous surgical tasks carried out by robots [30]. In telesurgery, one of the most addressed issues is the lack of force feedback in the existing telesurgical applications. This requires an extensive knowledge about the models of surgical tools, human tissues and their interaction. A comprehensive study on recent development in tool–tissue interaction modeling was presented by Misra *et al.* [31]. This survey focused on interaction types between models,

primarily addressing continuum mechanics based structures and finite element methods. Takács et al. extended the area of interest for telesurgical applications, summarizing the most important models used in practice in Table 1 [32].

Table 1 summarizes the basic properties of the most commonly used tool–tissue interaction models in some of the most relevant robotic surgery applications. The analysis included the use case of the model; the tissue model type, (which all can be categorized into the listing in this section), the tool model, (which, in most cases goes down to a rigid model, as the stiffness values of soft tissues are orders of magnitudes lower than that of the surgical tools), the feedback type as the future of the surgical robotics applications is most likely connected (to the development of telesurgery), sensor types (for mounting miniature sensors on the surgical instruments is still a great challenge, which is mostly solved by placing the sensor elements away from the tool tips, using transformations based on tool model data for realistic data response), and model complexity (which is essential for the investigation of further usability in a particular application due to computation capacity and time limitations).

Model	Used for	Tissue model	Tool model	Feedback type	Sensors	Model complexity	Author
1	Analyzing transparency under slave-link and joint flexibility	Rigid	Linear elastic	Force feedback to user's hand	Position and velocity sensors at tool tip	Varying, determined by the mechanical model of the tool	Tavakoli <i>et al.</i> 2009 [33]
2	Medical training through simulation in virtual reality	Mesh based FEA model, using modal analysis	rigid	Force and torque feedback, collision detection and detection of multiple tissue layers	Force and position sensors mounted on the tool, held by the user	The complexity is determined by the level of system reduction	Basdogan <i>et al.</i> 2004 [34]
		Real-time method of finite spheres				Simple, with minimized computational effort	
3	Real-time modeling of soft tissue response in computer simulation, using haptic device	Meshless, multi-layered three-parameter viscoelastic	rigid	Force feedback through Omega 7 haptic devices, visual feedback	No sensor mounted on the instrument	Advanced mechanical model	Bao <i>et al.</i> 2013 [35]
4	Detecting lumps in organ tissues (kidney, liver, heart)	7 different models, model validation on real tissues	rigid	No feedback to human user	1 DoF force feedback from point-to-point palpation	Increased accuracy with model complexity	Yamamoto 2011 [36]
5	Detection of lumps in prostate tissues, definition of forbidden regions	Manufactured artificial tissue	rigid	3D visual feedback generated with a stereo-vision system	Position, velocity and force sensors on slave side	Hunt–Crossley, a complex but accurate model	Yamamoto <i>et al.</i> 2012 [37]
6	Validation of a	Maxwell–	rigid	No feedback to	Force sensor at	Simple mechanical	Leong <i>et al.</i>

	mechanical model of liver tissue, interaction with scalpel blade	Kelvin viscoelastic, mechanical model		human user	the scalpel blade holder, position measurement.	model	2013 [27]
7	Force control on robotic-assisted surgery on beating heart	Kelvin–Boltzmann viscoelastic mechanical model	rigid	No feedback to human user	Force sensor at the end of instrument, position measurement	Simple mechanical model	Liu <i>et al.</i> 2011 [38]
8	Simulation of needle insertion in case of prostate brachytherapy	Mesh-based linear elastic model	Mesh-based linear elastic	No feedback to human user	No sensors mounted on the instrument	FEA model with improved re-meshing performance	Goksel <i>et al.</i> 2006 [39]
9	Analytical model and experimental validation of needle bending at insertion into soft tissues	Neo–Hookean model (hyperelastic), rupture model	Linear elastic	No feedback to human user	Unfiltered camera data for computation of bending curvature	Complex mechanical model, extended use of continuum-mechanics	Misra <i>et al.</i> 2010 [40]
10	Analytical model of tissue rupture due to needle insertion into porcine heart	Modified Kelvin viscoelastic model	rigid	No feedback to human user	Tension/compression sensing mounted on a linear actuator	Moderately complex, using 4 different models for insertion events	Mahvash <i>et al.</i> 2010 [41]
11	Analytical mechanical model for cable-driven tools interacting with artificial tissue	Use of artificial tissue, only contact force is measured	Lumped 1 DoF model with elastic cable	Feedback through DC motor encoders	Built-in encoders near the contact point, force gauge on the cable	Moderately complex, accounting for many mechanical properties	Kosari <i>et al.</i> 2012 [42]

5 Controllers for Teleoperation Systems

Along many different approaches, there has been a unified approach elaborated to resolve the control issues of telesurgical systems [43]. The design of controllers for teleoperation systems [14], [15], [44]-[50] is characterized by three unified features. These features will be pointed out as follows, along with details on the control system structures and controllers (algorithms) implemented in previous studies.

The first unified feature is the cascade control system structure given in Fig. 4. This control system structure points out the inner and the outer control loops. The inner loop plays its own role, in improvement of process dynamics and eventually compensation for some disturbances that act at that level. The inner controller is first designed and tuned, and the model of the inner control loop is processed such that to be used as a sub-system of the process in the design and tuning of the outer controller.

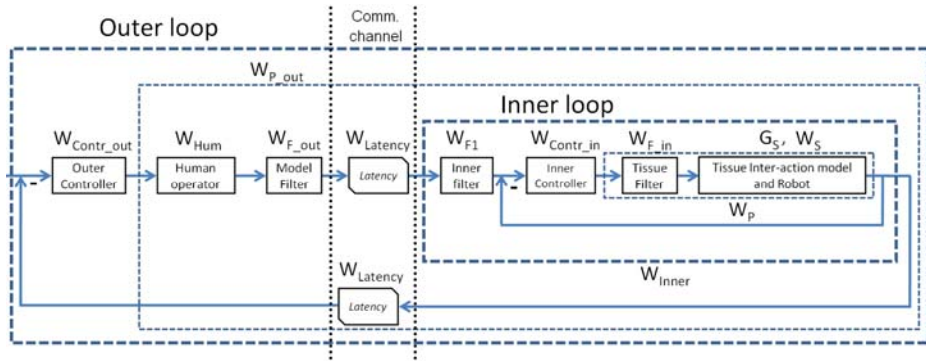


Figure 4

Cascade control system structure for teleoperation systems [41]

The second unified feature is the approximation of the time delays by first-order approximations in order to get transfer functions expressed in rational forms. This is advantageous because it enables the convenient design and tuning of the inner and outer controllers. In addition, Smith predictors can be further used for the same purpose.

The third unified feature is the use of the Extended Symmetrical Optimum (ESO) method [[51], [52]], to tune the parameters of the inner and outer PI and/or PID controllers. For example, using the inner PID controller transfer function:

$$W_{Contr_in}(s) = \frac{k_{Contr_in}}{s} (1 + T_{C1}s)(1 + T_{C2}s), \quad (6)$$

the tuning equations specific to the ESO method are:

$$k_{Contr_in} = \frac{1}{\beta\sqrt{\beta}k_pT_\Sigma^2}, \quad T_{C1} = T_1, \quad T_{C2} = \beta T_\Sigma, \quad (7)$$

where $\beta = \beta_{Inner}$, $4 \leq \beta_{Inner} \leq 20$, is the tuning parameter of the inner control loop, which is selected by the control system designer. The control system performance is further improved by reference input filters. The inner filter is pointed out in Fig. 4 and the outer filter is not.

However, the approximation of large time delays is not generally feasible. But the ESO method is sufficiently robust to handle the model mismatches.

The fuzzy controllers are structured as low-cost PI-, PD- or PID-fuzzy controllers. The linear behavior specific to PI, PD and PID controllers is fuzzified and the modal equivalences principle is generally applied to obtain tune the parameters of the fuzzy controllers. The low-cost controllers are characterized by simple controller structures and design approaches adapted from several results for PI-fuzzy controllers [53]-[1].

A general view of telesurgery problems for space applications is offered in [45]. The process models are considered as: basic human models (with a detailed explanation of the crossover model), the robot model (with simple second-order manipulator model), and the tissue characteristics are given through Fung's exponential force-stretch ratio curve. The ESO method is applied to design the linear controllers in the cascade control system structure.

The same models as those used in [45] are presented in [46], but there is no tissue model. PI and PID controllers tuned by the ESO method and predictive controllers are considered. There are no simulation results in [45] and [46].

The process models described in [46] are used in [44] as well. The time delays are handled in several ways using: empirical Ziegler-Nichols method (tested by simulation results), the ESO method (tested by simulation results), and PID-fuzzy controllers for both the inner and outer loops of the cascade control system structure (without simulation results).

An explanation of cascade control with the requirements is presented in [47]. An explanation of the Smith predictor, using a general open-loop stable transfer function is also given. The controller tuning by Kessler's empirical methods and the ESO method is explained, and the limitations are pointed out. Simulation results are given for Kessler's method employed with Smith predictor for large latencies, and the model parameters are not included.

A four-step design and tuning approach is suggested in [48], and it is accompanied by the detailed explanation of the cascade control system and of the controller design and tuning for both loops using the ESO method. A third-order model for the inner loop (slave robot) and a first-order time-delayed model for human user are used. The digital controllers are obtained using Tustin's method by digitizing

the continuous-time controllers. A PID–fuzzy controller is designed as the outer loop controller. Simulation results are included.

Overviews of the Takagi–Sugeno PID–fuzzy controllers, with a detailed theoretical background, and of cascade control systems and their role are carried out in [15]. The third-order slave robot model and the first-order time-delayed model for human user with Padé approximation are used. The controller design and tuning steps of the Takagi–Sugeno PID–fuzzy controller are presented in relation with the ESO method and the modal equivalences principle. A set of simulation results for a case study highlights the fuzzy control system performance improvement.

An overview of medical telerobotics in space is conducted in [49]. The controller design using Kessler’s and ESO method are designed using a second-order time-delayed human operator model and a third-order slave robot model. Controller design steps for both the inner and outer loops of the cascade control system structure are given. Simulation results focusing the robustness of Kessler’s method in terms of time delay are given.

An overview of the concept of telehealth is presented in [14] along with an introduction of the widely-used human operator and slave robot models. Fung’s exponential force-stretch ratio is employed for the tissue model. An overview of the controller design solutions is also presented, with focus on linear control approaches designed by the ESO and on fuzzy control approaches in terms of Takagi–Sugeno PID–fuzzy controllers. The fuzzy control system structures are tested by simulation.

An overview of the components of telesurgical systems and the current difficulties is given in [50]. Using a third-order slave robot model and the cascade control system structure, the outer loop Takagi–Sugeno PID–fuzzy controller are designed using an approach based on Linear Matrix Inequalities (LMIs). The LMIs are derived such that to guarantee the stability of the fuzzy control system. Simulation results are given for the proposed design approach.

Using the outer PID controller with the transfer function:

$$W_{Contr_out}(s) = \frac{k_{Contr_out}}{s} (1 + T_{C1out}s)(1 + T_{C2out}s), \quad (8)$$

the series structure of the Takagi–Sugeno PID–fuzzy controller is implemented as the series connection of PI– and PD–fuzzy controller. This leads to the low-cost design and tuning of the PID–fuzzy controller that results from the fuzzification of the linear PI and PD controllers obtained from the decomposition:

$$\begin{aligned}
 W_{Contr_out}(s) &= W_{PI}(s)W_{PD}(s), \\
 W_{PI}(s) &= \frac{k_{Contr_out}}{s}(1 + T_{C1out}s), \\
 W_{PD}(s) &= 1 + T_{C2out}s.
 \end{aligned} \tag{9}$$

The transfer function can also be decomposed using a parallel structure. The parallel structure has more flexibility. Both PID- fuzzy controller structures, serial and parallel, can be fuzzified partially by keeping some linear components.

6 Discussion

In the past years, telesurgery has become the focus of modern medicine, spreading onto several fields of science, including control engineering, informatics, biotechnology, medicine and many more. One of the most important roles of telesurgery is to synthesize these areas, creating a complex field of study, directly linked to applications. These require a solid foundation from the engineering point of view. This paper summarized the major components of telesurgical systems, presenting difficulties, challenges, approaches, methods and proposed solutions to the emerging control engineering problems. It is discussed, why mathematical modeling of these components individually and together as a whole is crucial in order to fully understand the behavior of these complex systems. It is important to note that whereas the mentioned models and approaches may differ from each other fundamentally, it is not their validity, but their applicability for the specific task that should be considered, when choosing the right model for a given problem.

Besides the most widely used human operator and slave robot models, a detailed table has been presented, listing some of the most relevant approaches to tool–tissue interaction modeling. An overview of the most important control methods for teleoperation systems has also been presented, extending the scope of this paper to real-life applications. Based on the discussed topics, an approach for modeling a complete telesurgical system was proposed. Future work includes the detailed investigation of each component, addressing both applicability and validity, and the integration of the listed components, applying the discussed control methods on the proposed models, verified by simulations and experiments.

Acknowledgement

This work was supported by the program “Partnerships in priority areas – PN II”, implemented with the support of MEN – UEFISCDI, project ADCOSBIO no. 211/2014, PN-II-PT-PCCA-2013-4-0544. Tamás Haidegger is a Bolyai Fellow of the Hungarian Academy of Sciences. This work has been supported by ACMIT

(Austrian Center for Medical Innovation and Technology), which is funded within the scope of the COMET (Competence Centers for Excellent Technologies) program of the Austrian Government.

References

- [1] T. Haidegger, “Surgical Robot Prototyping—System Development, Assessment and Clearance,” ch. 10 in T. Sobh and X. Xiong, Eds. *Prototyping of Robotic Systems: Applications of Design and Implementation*, IGI Book, Bridgeport, CT, pp. 288-326, 2012
- [2] T. Haidegger, J. Sándor and Z. Benyó, “Surgery in Space: the Future of Robotic Telesurgery,” *Surgical Endoscopy*, Vol. 25, Issue: 3, pp. 681-690, 2011
- [3] Mars One press release: “78,000 sign up for one-way mission to Mars” <http://mars-one.com>; May 7, 2013
- [4] M. Hoeckelmann, I. J. Rudas, P. Fiorini, F. Kirchner and T. Haidegger, “Current Capabilities and Development Potential in Surgical Robotics,” *International Journal of Advanced Robotic Systems*, p. 1, 2015
- [5] S. Jordán, Á. Takács, I. Rudas and T. Haidegger, “Modelling and Control Framework for Robotic Telesurgery,” in proc. of the 3rd *Joint Workshop on New Technologies for Computer/Robot Assisted Surgery (CRAS)*, Verona, 2013, pp. 89-92
- [6] "da Vinci Products FAQ". <http://phx.corporate-ir.net/phoenix.zhtml?c=122359&p=irol-faq#22324>. Intuitive Surgical. Accessed on 7 July, 2015
- [7] E. Flynn, “Telesurgery in the United States”. *Journal of Homeland Defense*, Vol. 6, pp. 24-28, 2005
- [8] C. Nguan, B. Miller, R. Patel et al., “Preclinical Remote Telesurgery Trial of a da Vinci Telesurgery Prototype,” *International Journal of Medical Robotics and Computer Assisted Surgery*, Vol. 4, pp. 304-309, 2008
- [9] H. H. King, B. Hannaford, K.-W. Kwok, G.-Z. Yang, P. Griffiths, A. Okamura et al., “Plugfest 2009: Global Interoperability in Telerobotics and Telemedicine,” in proc. of the *IEEE International Conference on Robotics and Automation (ICRA)*, Anchorage, pp. 1733-1738, 2010
- [10] N. J. Soper and G. M. Fried, “The Fundamentals of Laparoscopic Surgery,” *Journal of Gastrointestinal Surgery*, Vol. 12, No. 4, pp. 624-628, 2008
- [11] AT&T, “NGlobal Network Latency Averages”. Available: ipnetwork.bgtmo.ip.att.net/pws/global_network_avgs.html, 2013
- [12] J. Sándor, B. Lengyel, T. Haidegger, G. Saftics, G. Papp, Á. Nagy and Gy. Wéber, “Minimally Invasive Surgical Technologies: Challenges in

- Education and Training: Minimally Invasive Surgical Technologies,” *Asian Journal of Endoscopic Surgery*, Vol. 3, No. 3, pp. 101-108, May 2010
- [13] S. Butner and M. Ghodoussi, “Transforming a Surgical Robot for Human Telesurgery,” *IEEE Transactions on Robotics and Automation*, Vol. 19, No. 5, pp. 818-824, 2003
- [14] T. Haidegger, L. Kovács, R.-E. Precup, B. Benyó, Z. Benyó and S. Preitl, “Simulation and Control for Telerobots in Space Medicine,” *Acta Astronautica*, Vol. 81, No. 1, pp. 390-402, 2012
- [15] R.-E. Precup, T. Haidegger, L. Kovács, A. S. Paul, S. Preitl and Z. Benyó, “Fuzzy Control Solution for Telesurgical Applications,” *Applied and Computational Mathematics. An International Journal (ACM)*, Vol. 11, No. 3, pp. 378-397, 2012
- [16] R. A. Hess and A. Modjtahedzadeh, “A Control Theoretic Model of Driver Steering Behavior,” *IEEE Control Systems Magazine*, Vol. 10, No. 5, pp. 3-8, 1990
- [17] D. L. Kleinman, S. Baron and W. H. Levison, “An Optimal Control Model of Human Response Part I: Theory and Validation”. *Automatica*, Vol. 6, No. 3, pp. 357-369, 1970
- [18] G. N. Ornstein, “The Automatic Analog Determination of Human Transfer Function Coefficients.” *Medical Electronics and Biological Engineering*, Vol. 1, No. 3, pp. 377-387, 1963
- [19] C. C. MacAdam, “Understanding and Modeling the Human Driver”. *Vehicle System Dynamics*, Vol. 40, No. 1-3, pp. 101-134, 2003
- [20] R. G. Costello and T. J. Higgins, “An Inclusive Classified Bibliography Pertaining to Modeling the Human Operator as an Element in an Automatic Control System,” *IEEE Transactions on Human Factors in Electronics*, Vol. HFE-7, No. 4, pp. 174-181, Dec. 1966
- [21] C. C. MacAdam, “Development of a Driver Model for Near/At-Limit Vehicle Handling”, Technical report, UMTRI-2001-43. Sponsored by the General Motors Corporation, pp. 1-122, 2001
- [22] J. H. Chien, M. M. Tiwari, I. H. Suh, D. Oleynikov and K.-C. Siu, “Accuracy and Speed Trade-Off in Robot-assisted Surgery,” *International Journal of Medical Robotics Assisted Surgery*, Vol. 6, No. 5, pp. 324-329, 2010
- [23] L. W. Sun, F. Van Meer, Y. Bailly and C. K. Yeung, “Design and Development of a Da Vinci Surgical System Simulator,” in proc. of the *IEEE International Conference on Mechatronics and Automation (ICMA)*, pp. 1050-1055, 2007
- [24] A. A. Syed, X. G. Duan, X. Kong, M. Li, Y. Wang and Q. Huang, “6-DOF Maxillofacial Surgical Robotic Manipulator Controlled By Haptic Device,”

- in proc. of the 9th Intl. Conf. on Ubiquitous Robots and Ambient Intelligence (URAI 2012), Daejeon, pp. 71-74, 2012
- [25] L. Pelyhe, and P. Nagy. “Relative Visibility of the Diagnostic Catheter.” *Acta Polytechnica Hungarica* Vol. 11, No. 10, pp. 79-95 (2014)
 - [26] N. Famaey and J. Vander Sloten, “Soft Tissue Modelling for Applications in Virtual Surgery and Surgical Robotics”, *Computer Methods in Biomechanics and Biomedical Engineering*, Vol. 11, no. 4, pp. 351-366, 2008
 - [27] F. Leong, W. Huang and C. Chui, “Modelling and Analysis of Coagulated Liver Tissue and its Interaction with a Scalpel Blade,” *Medical and Biological Engineering Computing*, Vol. 51, pp. 687-695, 2013
 - [28] Á. Takács, J. K. Tar, T. Haidegger and I. J. Rudas, “Applicability of the Maxwell–Kelvin Model in Soft Tissue Parameter Estimation,” in proc. of the *IEEE 12th Intl. Symp. on Intelligent Systems and Informatics (SISY)*, 2014, pp. 115-119
 - [29] Á. Takács, P. Galambos, I. J. Rudas and T. Haidegger, “Nonlinear Soft Tissue Models and Force Control for Medical Cyber-Physical Systems,” in proc. of the *IEEE International Conference on Systems, Man and Cybernetics*, 2015 (accepted)
 - [30] I. Bíró and G. Fekete. “Approximate Method for Determining the Axis of Finite Rotation of Human Knee Joint.” *Acta Polytechnica Hungarica*, Vol. 11, No. 9, pp. 61-74, 2014
 - [31] S. Misra, K. T. Ramesh and Allison M. Okamura, “Modeling of Tool–Tissue Interactions for Computer-based Surgical Simulation: A Literature Review,” *Presence: Teleoperators and Virtual Environments*, Vol. 17, No. 5, pp. 463-491, 2008
 - [32] A. Takacs, S. Jordan, R.-E. Precup, L. Kovacs, J. Tar, I. Rudas and T. Haidegger, “Review of Tool–Tissue Interaction Models for Robotic Surgery Applications,” in proc. of the *IEEE 12th Intl. Symp. on Applied Machine Intelligence and Informatics (SAMi)*, 2014, pp. 339-344
 - [33] M. Tavakoli and R. D. Howe, “Haptic Effects of Surgical Teleoperator Flexibility,” *The International Journal of Robotics Research*, Vol. 28, No. 10, pp. 1289-1302, 2009
 - [34] C. Basdogan, S. De, J. Kim et al., “Haptics in Minimally Invasive Surgical Simulation and Training”, *IEEE Computer Graphics and Applications*, Vol. 24, No. 2, pp. 56-64, 2004
 - [35] Y. Bao, D. Wu, Z. Yan and Z. Du, “A New Hybrid Viscoelastic Soft Tissue Model based on Meshless Method for Haptic Surgical Simulation,” *The Open Biomedical Engineering Journal*, Vol. 7, pp. 116-124, 2013

- [36] T. Yamamoto, "Applying Tissue Models in Teleoperated Robot-Assisted Surgery," PhD dissertation, Johns Hopkins University, Baltimore, MD, January, 2011
- [37] T. Yamamoto, N. Abolhassani, S. Jung et al., "Augmented Reality and Haptic Interfaces for Robot-assisted Surgery," *The International Journal of Medical Robotics and Computer Assisted Surgery*, Vol. 8, pp. 45-56, 2012
- [38] C. Liu, P. Moreira, N. Zemiti and P. Poignet, "3D Force Control for Robotic-assisted Beating Heart Surgery Based on Viscoelastic Tissue Model," in proc. of the *Intl. Conf. of the IEEE Engineering in Medicine and Biology Society*, pp. 7054-7058, 2011
- [39] O. Goksel, S. E. Salcudean and S. P. DiMaio, "3D Simulation of Needle-Tissue Interaction with Application to Prostate Brachytherapy", *Computer Aided Surgery*, Vol. 11, No. 6, pp. 279-288, 2006
- [40] S. Misra, K. B. Reed, B. W. Schafer et al., "Mechanics of Flexible Needles Robotically Steered through Soft Tissue", *The International Journal of Robotics Research*, Vol. 29, No. 13, pp. 1640-1660, 2010
- [41] M Mahvash and P. E. Dupont, "Mechanics of Dynamic Needle Insertion into a Biological Material," *IEEE Transactions on Biomedical Engineering*, Vol. 57, No. 4, pp. 934-943, 2010
- [42] S. N. Kosari, S. Ramadurai, H. J. Chizeck and B. Hannaford, "Robotic Compression of Soft Tissue," in proc. of the *IEEE International Conference on Robotics and Automation*, St. Paul, MN, 2012. pp. 4654-4659
- [43] Hokayem, Peter F., and Mark W. Spong. "Bilateral Teleoperation: An Historical Survey." *Automatica*, Vol. 42, No. 12, pp. 2035-2057, 2006
- [44] T. Haidegger, L. Kovács, S. Preitl, R.-E. Precup, B. Benyó, Z. Benyó, "Controller Design Solutions for Long Distance Telesurgical Applications," *International Journal of Artificial Intelligence*, Vol. 6, No. S11, pp. 48-71, 2011
- [45] T. Haidegger, L. Kovács, S. Preitl, R.-E. Precup, A. Kovács, B. Benyó and Z. Benyó, "Cascade Control for Telehealth Applications," *Scientific Bulletin of the "Politehnica" University of Timisoara, Transactions on Automatic Control and Computer Science*, Vol. 55 (69), No. 4, pp. 223-232, 2010
- [46] T. Haidegger, L. Kovács, S. Preitl, R.-E. Precup, A. Kovács, B. Benyó and Z. Benyó, "Modeling and Control Aspects of Long Distance Telesurgical Applications," in proc. of the *2010 Intl. Joint Conf. on Computational Cybernetics and Technical Informatics (ICCC-CONTI)*, Timișoara, 2010, pp. 197-202

- [47] T. Haidegger, L. Kovács, H. Varga, S. Preitl, R.-E. Precup, B. Benyó and Z. Benyó, "Extended Symmetrical Optimum Combined with Smith-Predictor for Telehealth Applications: a Case Study," in *proc. of the 3rd Intl. Conf. on Recent Achievements in Mechatronics, Automation, Computer Sciences and Robotics (MACRo)*, Tirgu-Mures, 2011, pp. 263-272
- [48] R.-E. Precup, L. Kovács, T. Haidegger, S. Preitl, A. Kovács, B. Benyó, E. Borbely and Z. Benyó, "Time Delay Compensation by Fuzzy Control in the Case of Master–Slave Telesurgery," in *proc. of the 6th IEEE Intl. Symp. on Applied Computational Intelligence and Informatics (SACI)*, Timișoara, 2011, pp. 305-310
- [49] T. Haidegger, L. Kovács, R.-E. Precup, S. Preitl, B. Benyó and Z. Benyó, "Cascade Control for Telerobotic Systems Serving Space Medicine," in *proc. of the 18th IFAC World Congress*, Milano, 2011, pp. 3759-3764
- [50] R.-E. Precup, T. Haidegger and L. Kovács, "Stable Hybrid Fuzzy Controller-based Architecture for Robotic Telesurgery Systems," *International Journal of Computational Intelligence and Pattern Recognition*, Vol. 1, No. 1, pp. 61-76, 2014
- [51] S. Preitl and R.-E. Precup, "On the Algorithmic Design of a Class of Control Systems Based on Providing the Symmetry of Open-Loop Bode Plots," *Scientific Bulletin of the "Politehnica" University of Timisoara, Transactions on Automatic Control and Computer Science*, Vol. 41 (55), No. 2, pp. 47-55, 1996
- [52] S. Preitl and R.-E. Precup, "An Extension of Tuning Relations After Symmetrical Optimum Method for PI and PID Controllers," *Automatica*, Vol. 35, No. 10, pp. 1731-1736, 1999
- [53] S. Preitl and R.-E. Precup, *Introducerea in Conducerea Fuzzy a Proceselor*, Editura Tehnica, Bucharest, 1997
- [54] R.-E. Precup, S. Preitl, M. Balas and V. Balas, "Fuzzy Controllers for Tire Slip Control in Anti-lock Braking Systems," in *proc. of the IEEE International Conference on Fuzzy Systems (FUZZ-IEEE 2004)*, Budapest, 2004, Vol. 3, pp. 1317-1322
- [55] R.-E. Precup and S. Preitl, "PI-Fuzzy Controllers for Integral Plants to Ensure Robust Stability," *Information Sciences*, Vol. 177, No. 20, pp. 4410-4429, 2007
- [56] R.-E. Precup, S. Preitl, M.-B. Radac, E. M. Petriu, C.-A. Dragos and J. K. Tar, "Experiment-based Teaching in Advanced Control Engineering," *IEEE Transactions on Education*, Vol. 54, No. 3, pp. 345-355, 2011
- [57] R.-E. Precup, M. L. Tomescu, M.-B. Radac, E. M. Petriu, S. Preitl and C.-A. Dragos, "Iterative Performance Improvement of Fuzzy Control Systems for Three Tank Systems," *Expert Systems with Applications*, Vol. 39, No. 9, pp. 8288-8299, 2012

Integral Model of Strategic Management: Identification of Potential Synergies

Aleksandar M. Dejanović¹, Slavka T. Nikolić², Jelena Stanković²

¹ Modern Business School, Narodnih Heroja 30, 11070 Novi Beograd, Serbia,
email: aleksandar.dejanovic@mbs.edu.rs

² Universtiy of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića
6, 21000 Novi Sad, Serbia; e-mail: snikolic@uns.ac.rs, stankovicj@uns.ac.rs

Abstract: The main goal of this study is the construction of an integral model of strategic management, based on the comparative analysis among many well-established management concepts. It was found that new product development, total quality management (TQM), brand management and customer relationship management (CRM) share common characteristics such as strategic dimension, corporate culture dimension, customer focus, etc. Thus, the object of this paper refers to the potential of connection of these managerial concepts into a single Integral model of strategic management together with a measuring system based on Balanced Scorecard (BSC). After the relevant literature review and theoretical constructs on a conceptual level, the model has been tested in practice. The experiment has proved that the Integral model of strategic management is applicable and it positively impacts on a company's performance.

Keywords: Integral Model of Strategic Management; New Product Development; Total Quality Management; Brand Management; Customer Relationship Management

1 Introduction

In the field of strategic management, both in theory and practice, there are many well-established management concepts, models and techniques. Based on the comparative analysis, it was found that among them there are a lot of similarities. Thus, it was discovered that new product development, total quality management, brand management and customer relationship management share common characteristics such as strategic dimension, relying on corporate culture, customer focus, continuous improvement and measurability, i.e. manageability. These common features suggest the possibility of connection of these managerial concepts into a single integral model of strategic management.

The aim of this research is the construction and function of the integral model of strategic management which encompasses four identified elements: (1) New Product Development; (2) Total Quality Management-TQM; (3) Brand

Management; (4) Customer Relationship Management-CRM. As one of the requirements of strategic management, a measuring system based on Balanced Scorecard-BSC has been installed into this model. All the mentioned elements are well-known in theory and practice, but their combination and cross-influence represent a novelty in the field of strategic management. Therefore, the construction of an integral model of strategic management of these concepts can be considered as a first-class theoretical and practical challenge.

The primary goal of this research is to demonstrate the functionality of the integral model of strategic management in real conditions. The goal of the research set in this way implies that the integral model is implemented in practice and its effects are measured (i.e. how it affects the organization's performance). According to the relevant literature review as well as the research results obtained in the experimental company, advantages and disadvantages of this model should be identified, and in this regard areas for progress and improvement should be defined. This research should also foster theoretical discussion and initiate new research as well as send a signal to companies that are ready to redefine their strategies.

The need for new solutions in strategic management is especially dominate during periods of economic crisis when most companies lose strategic orientation. Managers of these companies, as a response to the crisis, instinctively seek shelter, hoping the disturbances will not last for a long time. Integral model of strategic management has a completely different paradigm, which should be illustrated by the results of this research and therefore recommended for use in practice.

This paper is organized as follows. The first part presents the subject of this research in a wider context as well as related literature used for the construction of integral model of strategic management. The second part is devoted to model development. It describes its structure, basic characteristics and logic of functioning. Then, we introduce the research methodology used in this research, present the main findings, discuss the model implications and finally conclude our study with a proposal for further research.

2 Theoretical Background

Sudden and radical market trends constantly change market landscape. Old rules and "maps" quickly become obsolete. Therefore, during the past few decades, many new business models and concepts appeared in theory and practice. New solutions are mainly directed towards integrated management systems, which combine all the components of the business into a coherent whole. Their basic characteristic is that they can simultaneously realize common functions of associated subsystems, as well as achieve specific goals in accordance with the requirements of interested parties (stakeholders).

The study of relevant literature reveals that there are a lot more papers on the integration of standardized management systems that integrate those management systems in accordance with standards such as ISO 9000, ISO 14000/EMAS, OHSAS 18000, HACCP/ISO 22000, ISO 27000 and SA 8000/ISO 26000. Among the first to start the study of this issue were: Miles and Russell [32], Dale and Wilkinson [11], Karapetrovic [28], Zutshi and Sohal [43], Jørgensen et al. [26], as well as Abrahamson, Hansson and Isaksson [1]. This "surge" has occupied the attention of academics but also managers in practice, which can be seen in a growing number of organizations, to have two or more valid certificates of compliance required by different standards. On the other hand, models for the integration of non-standardized management systems are quite neglected. In this way, the gap in the system of knowledge has been observed and this study was initiated.

According to models of integrated standardized management systems, the integral model of strategic management has been designed. This structured model includes: (1) New Product Development; (2) Total Quality Management-TQM; (3) Brand Management and (4) Customer Relationship Management-CRM. A measuring system based on Balanced Scorecard (BSC) has also been installed into this model.

By reviewing the relevant literature, it can be seen that all these elements have some common characteristics which enable them to be connected. *Firstly*, all of the business concepts that are connected in the model have a strategic dimension. Managing the development of a new product requires a foothold in the strategy [10], [8]. Recent studies have explicitly shown that companies which have clearly defined objectives in the strategy of new product development achieve significantly better results compared to competitors without strategic orientation [9]. The same can be concluded for the total quality management. This business philosophy also involves a strategic approach [15], [39], [36]. Successful brand management is also unthinkable with adequate strategies [29], [21]. Finally, consumer relationship management is a strategy, not sales tactics or technology sales [16], [35]. Therefore, each element of the integral model is part of the development of the organization in a time span of 3 to 5 years. Their implementation implies significant investment and engagement of resources, while requiring dedication, i.e. leadership of most responsible leaders in the company. *Secondly*, all of the business concepts that are integrated in the model have support in the corporate culture. For example, managing the development of a new product depends on an innovative climate within the company, and that innovative climate is the reflection of the corporate culture [25]. The total quality management system is based on solid documentation, written rules - the rules stemming from the corporate culture [23], [34]. Likewise, corporate culture determines invisible brand elements [42]. Finally, corporate culture is directly dependent on the quality of the relationship between companies and customers [38], [24]. *Thirdly*, every business concept in the model is directed towards

consumers. When new products are being developed, the requirements, needs, desires and expectations of consumers are the starting point [4], [41]. Also, one of the fundamental principles of total quality management to be met is fulfilling and overcoming consumer expectations. Within this theoretical context, a specific technique has been developed, QFD (Quality Function Deployment), which serves to "translate" the demands of consumers into technical, i.e. product specifications. According too many authors, this technique is one of the most important TQM tools [2], [17], [7]. Brand management is by definition customer orientated [13], [40] as well as CRM [18], [19], [22].

Based on a thorough review of the relevant literature, it was found that all elements that make the integral model of strategic management have their theoretical and practical pedigree. Studying the basic characteristics of the selected elements it was observed that there are a lot of similarities among them (strategic dimension, corporate culture dimension and customer focused orientation), which reveals the possibility of their interconnection. With the respect to the current management literature, this study extends recent work in the field of strategic management and advocates for the synchronization of well-known business concepts: new product development management, total quality management, brand management and customer relationship management. Focusing on these theoretically compatible managerial concepts, together with the measuring system based on balanced scorecards, we have coordinated them and merged them into a single integral model of strategic management.

3 Construction of Integral Model of Strategic Management

Integral model of strategic management proposes the integration of four selected elements and a measuring system. Each element has its own identity that makes it special and different from the others. These specific features, i.e. the differences are preserved in the model. It is important that these differences are not too distinct that they are not irreconcilable, but rather complement each other. Differences contribute the model to be richer, more layered, more dynamic, but also more complex and unstable. On the other hand, concerning integral model there are many mutual characteristics and similarities between the elements. Cohesion and sustainability of this model are built on that.

Architecture of the integral model of strategic management does not have pyramidal shape, because in this model the elements are not arranged according to hierarchy. Relations between the elements are not based on superiority, or inferiority. In this model there are no important and less important elements. Their roles are different but equal. Minimization of any element would significantly diminish the basic idea of functioning of integral model of strategic management. Such a hypothetical configuration can best be shown by Venn diagram:

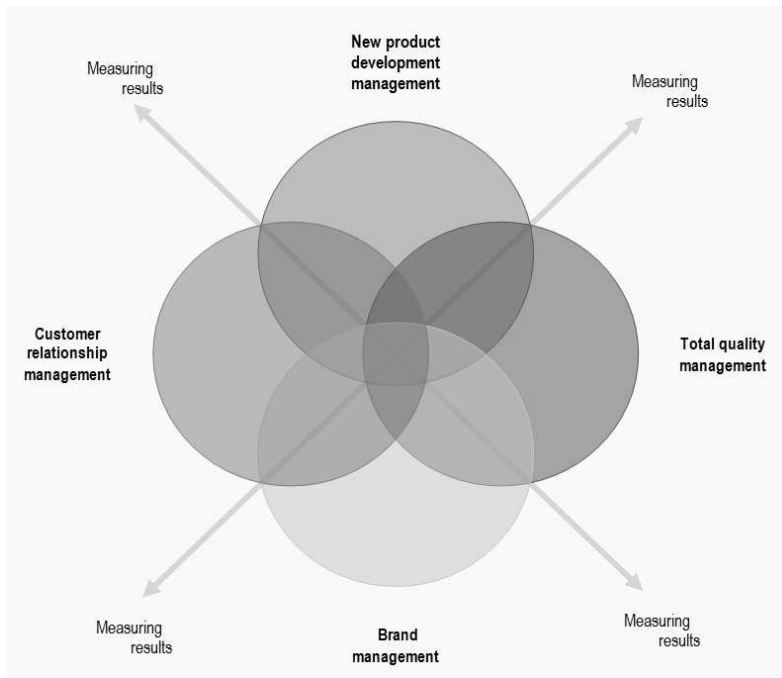


Figure 1

Construction of the integral model of strategic management

It should be emphasized that an integral model of strategic management is not a simple sum of the four mentioned elements. The construction of this model is not mechanical, i.e. mathematical. The model cannot be obtained by placing the elements one upon the other. It is not possible, because each individual element is in fact very jagged, complex in its structure and has a different shape. If all the elements were connected only on the basis of simple addition, "mega" model would occur, which would be very bulky, complicated, confusing and difficult to manage. Such a model would be unsuitable for the application and also unstable. In this context the fundamental question arises - how to construct the model and adapt it to the needs of a company. This question may be set up differently - how to "pack" four complex elements in the appropriate form and guide, i.e. synchronize their operation. This can be achieved by extracting the essence out of each element. This will provide a number of key components - basic characteristics of each concept that can be easily combined. Again, it is important to emphasize that these extracts do not add up, but mix and would result in a "recipe", i.e. the proportion of individual components depends on the specific needs and characteristics of a company.

3.1 Basic Characteristics of Integral Model of Strategic Management

The first element - New product development - is specific because it has in its essence a creative process that starts with an idea and ends with the launch of a new product on the market. Its basic characteristic is *creativity* [6], [20]. This creativity is embedded in a formalized and structured algorithm in order to manage the creative process, but this does not change the substance. The most important part of the new product development is stimulation of new ideas, choice of high potential ideas and their conversion into new products and services intended for the market in the most efficient way [30]. Companies that do not want to copy or imitate their competition cannot survive without creativity. In addition, this creativity has to be focused on the needs, requirements, desires and expectations of customers.

The second element - Total Quality Management - implies quality improvement in a company on the basis of process and system approach [5]. In this sense, the importance of documentation is emphasized (policies, plans, procedures, instructions, records), responsibilities identification, constant comparison with established specifications and remove non-conformities [3]. According to this, it can be concluded that the basic characteristic of quality management is *administrative and organizational orderliness*. It is necessary for every business system. A company that does not have developed organizational and administrative infrastructure can achieve accidental short-term success. Probability for such a company to achieve set goals can be compared to probability in games of chance.

The third element - Brand management - has many dimensions, but it is mostly focused on the presentation of the company and its products. Brand reflects the exterior (visible elements), but also the personality, i.e. the character of the company (invisible elements). Visible elements are first to be detected and they create the impression, and the invisible elements complement this impression and can cause deeper psychological reactions of customers [12]. This way brand essence is expressed: *particularity/uniqueness*. It is the foundation on which its position is built and strengthened in customers' minds [37]. Strong brand strengthens the company, encourages its development and ensures competitive advantage. On the other hand, a weak brand is a handicap for the company, as it reduces its chances for development. In such circumstances, the company is doomed to anonymity and is usually referred to as "other". These companies are forced to fight for survival by lowering of costs and low prices. Wherein, there is a limit to which costs can be reduced without threatening the functioning of the company. Therefore, brand management, i.e. the reaction, maintenance and improvement of its particularity and uniqueness represents the imperative in modern business.

The fourth element - Customer relationship management - includes the interaction between the company and customer in which values are created and exchanged [33]. Through this interaction, the relations between company and customer are established, maintained and improved. The essence of this relationship is mutual *confidence*. Of course, in addition to confidence among companies and customers a whole range of relationships is created (affection, understanding, respect) but without confidence, as the key component, the overall relationship will be destroyed [31]. The creation of confidence implies the respect of the obligations taken on and represents one of the fundamental elements of perception of customers towards the companies, i.e. brands. It takes time to build it, but can be lost fast. If it is once lost, it is difficult to be re-built. Therefore, in order to be successful on the market a company has to go through the phase of gaining customers' confidence.

Hence, creativity, administrative and organizational orderliness, particularity/uniqueness and confidence, as basic characteristics of elements were built in the integral model of strategic management.

Creativity is built into the integral model through new product development. Quality management brings administrative and organizational orderliness to the company, while brand management entries particularity and uniqueness. Thanks to customer relationship management the company gains confidence (Figure 2).

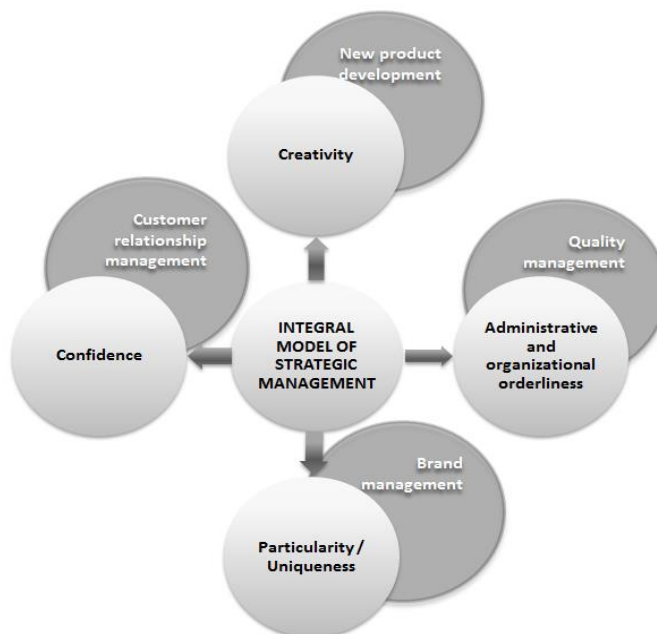


Figure 2
Basic Characteristics of the Integral Model of Strategic Management

Different characteristics of the elements that make up an integral model of strategic management determine its functioning. These characteristics should not be viewed in isolation, but through interaction. Greater degree of compatibility guarantees more harmony in the functioning of integral models, and vice versa - lower compatibility of characteristics causes more imbalances. However, dynamic models necessarily have imbalance in themselves. Internal differences drive models. Strategic development management based on any model involves conflict and harmony, which is imbalance and restoration at a higher level.

3.2 Integral Model of Strategic Management - Circle of Functioning

The basic attributes of each element indicate what the integral model of strategic management looks like, but they also determine the way it functions. Activities can be presented in the form of a circular flow starting from the creative phase up to the measurement of results, i.e. planning a new cycle.

The circular flow of activities in integral model of strategic management resembles helio-centric system (Figure 3). However, the focus of this model is the customer.¹ All of these activities "revolve" around this center in order to establish, support and promote the organization's relationship with customers. If any of these activities goes out of this orbit and loses its focus on the customer, then the model will function eccentrically. In the extreme case, if the centrifugal forces in the company are so strong (resistance to change) and move away the activities from this center, the model will disintegrate.

The logic of this model is linking of various processes and functions of the organization. The cycle begins with a creative impulse (first sequence - Create/Innovate). Development of a new product begins, process or organization is improved. Something new is created. In the second sequence, this creative energy fits into the appropriate structure (TQM). This system, with its own rules, must not "choke" or obstruct creativity, but only direct it to appropriate standards - as customers demand or expect it. After all, the first principle of quality management systems according to the ISO 9000 is the focus on the customer. In addition, thanks to the developed documentation basis of the quality system, the company receives administrative and organizational orderliness. The third sequence (Brand) involves fitting a new product or innovation in brand architecture in order to strengthen the brand, add it a new content, define new or confirm existing brand promise. In this way, a brand broadcasts a new or updated message to customers. In the following sequence the emphasis is on CRM activities.

¹ That is why this model is in Anglo-american literature often called "Customer Centric". Some authors use the term "Customer Focused". There is no significant difference between these terms [14].

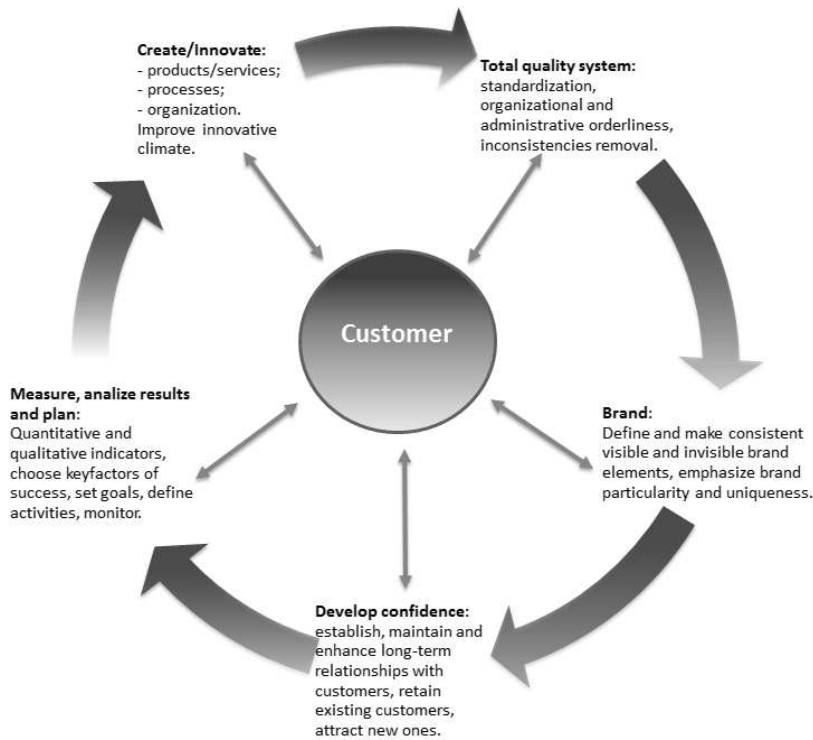


Figure 3

Integral Model of Strategic Management - Circle of Activities

All that has been done in previous phases merges with the activities aimed at establishing, maintaining and developing the relationship with customers. At the same time, insisting on confidence strengthening is a key component of the relationship between company and customers. Finally, measurement of company performance follows based on the BSC methodology, analysis and formulation of conclusions, lessons, making plans to improve the next cycle. Such an interpretation is reminiscent of Deming cycle or as in theory also called PDCA cycle (**P**lan; **D**o; **C**heck and **A**ct).

4 Research Methodology

The main hypothesis set in this research is that the integral model of strategic management has a positive impact on company performance. This hypothesis was tested in an experiment which was carried out under real market conditions during the period 2011 - 2013. So, measurements have lasted for three years, and in the field of research the BSC measurement system was used which involved five

perspectives of structured model and a total of 21 key performance indicators (KPI):

- Perspective of creativity;
- Perspective of quality;
- Perspective of brand strength;
- Perspective of customers;
- Financial perspective

The perspective of creativity, in most of its features, matches the perspective of learning and growth in the original Kaplan Norton model [27]. It shows the level of development of innovative climate in the company, or creative and intellectual capacity of the company. Within this perspective four key performance indicators are defined: (1) Employee satisfaction; (2) Training and education of employees; (3) Investment in technological development; (4) Degree of automation. The first two indicators are related to human resources and the other two on technical and technological resources. These indicators reflect the company's ability to learn and progress.

The perspective of quality is broad and shows the state of the quality system of the company. However, this perspective focuses on processes, and administrative or organizational orderliness of the company. In this regard, the following key indicators are determined: (1) the process compliance with the requirements of ISO 9001:2008; (2) the quality of products; (3) quality of service; (4) implementation of service support as an important component of quality. This perspective represents the novelty, because it is not provided in the Kaplan-Norton model, and it was developed according to the needs of the integral model of strategic management. Identified indicators were chosen because each of them strongly reflects the level of development and characteristics of the quality system in organization.

Perspective of brand strength illustrates the position and prospects of the brand in the market. In this context four key performance indicators were defined: (1) investments in advertising; (2) an internet presentation as a channel of communication; (3) participation in social networks; (4) expression of corporate social responsibility. This perspective also represents original contribution to the Kaplan-Norton model. The first indicator was chosen because investment in advertising contributes to building a strong brand, "nourishes and refreshes" the brand in the minds of users. The second and third indicators reflect the growing importance of the Internet and social networks (Facebook) in brand development. The fourth indicator (Corporate Social Responsibility - CSR) illustrates the relationship between the company and community, which is an important component of a brand.

The perspective of customers shows how customers perceive the company, and reveals a wide range of relationships between companies and customers, as defined by Kaplan-Norton model. Key performance indicators in this view are: (1) customers' satisfaction; (2) customers' loyalty; (3) the volume of sales; (4) the profitability of sales. Logically, each of these indicators convincingly testifies about the quality of the relationship between businesses and customers, in both qualitative and quantitative manner.

Financial perspective gives an insight into the financial impact of implemented changes in the company. Key performance indicators that monitor the financial perspective are: (1) collections; (2) payments; (3) structure of income; (4) structure of liabilities; (5) financial results. Based on Kaplan-Norton model, these five identified indicators, with high level of reliability, can assess financial condition of the company.

Key performance indicators have been chosen based on goals set in the strategic company plan, which is thoroughly consistent with the theoretical assumptions, referring to recommendations of Kaplan and Norton [27]. These indicators clearly and precisely show how far a company is from the defined strategic goals. Apart from that, the previously mentioned indicators are incorporated into a strategic map that links the activities and goals of a company. Due to that, a company can convert its initiatives and resources (tangible and non-tangible) into results. Using this measuring system, in other words control of strategy implementation, a company gets an opportunity to discover deviations in functioning of the integral model of strategic management very early and take corrective measures beforehand.

The number of key performance indicators is based on company practice in applying the BSC system. Namely, practice has shown that less than 15 indicators are not enough to show the whole picture of the company, and that more than 25 indicators complicate the monitoring and control too much. Therefore, commonly between 20 and 25 indicators are picked, as it was the case during the realization of this research.

According to the plan of the research, measurements are realized in company named "Positive" in Novi Sad, Serbia. This company was founded at the beginning of year 2000 and deals with selling computers and computer equipment, designing and production of complex computer networks, also technical support which is maintenance of IT equipment and installations. The company had 28 employees in its private property at the end of 2013. "Positive" company has been chosen as a partner in this research for the following reasons: (1) this company has implemented the integral model of strategic management; (2) the company uses the BSC software, which represents an important precondition for realization of the research; (3) the company has standardized its business with ISO 9000 and ISO 27000 standards which has been confirmed by valid certificates; (4) in this company an innovative environment has been made due to continual investments

in professional training of employees, then growth and successful adaptation of technical and organizational improvements.

The research achieved was very complex. “Positive” company was first supposed to implement the integral model of strategic management. This model was introduced in the second half of 2010. A solid base for introducing this model was the existing organizational culture and managing system in the company. The dominant type of organizational culture (task culture) suited the realization of this experiment. Everything has been subordinated to problem solving, in other words to realization of projects and tasks, and emphasis has been set on getting results. Team type or in other words project type of work has been affirmed. Power in the company has been decentralized, because some individuals had high deciding autonomy thanks to their competence. Communication between the employees has become open and informal. Organizations in which this type of culture is dominant don’t have pronounced organizational boundaries, they are very flexible and are ready for changes. Managing system of the company has been based on managing logics that is consistent to the demands of ISO 9001:2008 standards.

The first step in implementation of integral model of strategic management into “Positive” company was shaping the developing strategy for the 2011-2013 period. Within that, the position of the company was analyzed, and then new visions and missions were defined, as well as key values that the company would believe in and insist to affirm. In the second phase the main strategic choices and basic goals of the company were defined. These goals were grouped into five perspectives, according to the logics of the integral model of strategic management. After that, in the third phase, a measuring system was constructed, key performance indicators were chosen and a reporting system was set. That gave a possibility for following, supervision and control of integral model functionality. During the observed period, data were collected and the accomplished results were analyzed, along with the constant consultations with the company management.

Data were derived from the information system of the chosen company, using modern software tools, especially software package Business Navigator ver. 2:37, which is based on OLAP (Online Analytical Processing) technology. This software, for its basic characteristics and logics is one of the Balanced Scorecard applications because it combines several different (mutually connected) modules such as financial management, procurement and sales, production management, human resources management, marketing management, etc.

Measurements of the achieved results are realized simultaneously with the implementation of the model (beginning of 2011). Decreasing three-year trend of basic business indicators would be a reliable signal to show that an integral model of strategic management is not fulfilling its purpose. However, the increasing trend would point to a conclusion that this model affects the improvement of company performance (accepting the hypothesis). Fluctuation of trend (change of

direction) would show that the long-term phenomenon trend would not be stable and in this case reliable conclusions on the functioning of the integral model could not be established, i.e. the hypothesis accepted or rejected.

5 Results

Completed research confirmed the hypothesis set in the plan of the research. The results of the experiment, i.e. analyses of data on the basis of measurement of three-year period (2011-2013), have shown that the integral model of strategic management is functional, i.e. that it influences the improvement of company performance. Most of the selected key performance indicators that are defined in the BSC measurement system convincingly testify in favor of this conclusion (Table 1).

Table 1
Key Performance Indicators in BSC Measuring System

Key performance indicators	Hypothesis acceptance			Note
	Yes	Partially	No	
<i>Perspective of creativity</i>				
KPI 1: Employee satisfaction	x			Employee satisfaction increased
KPI 2: Employee training		x		Growth trend not formed
KPI 3: Tech. development	x			High level of innovation investment
KPI 4: IT support	x			≈90% of the process covered by IT support
<i>Perspective of quality</i>				
KPI 5: ISO 9001:2008	x			Compliance with standard
KPI 6: Product quality	x			Fewer complaints on product quality
KPI 7: Service quality	x			Fewer complaints on service quality
KPI 8: Service support	x			Service support efficiency increased
<i>Perspective of brand strength</i>				
KPI 9: Advertising	x			Advertising budget for 2013 increased
KPI 10: Internet		x		Internet site visits - trend fluctuation
KPI 11: Social networks	x			Rising trend of social networks indicators
KPI 12: CSR	x			Increased investments for these purposes
<i>Perspective of customers</i>				
KPI 13: Customer satisfaction	x			Customer satisfaction increased
KPI 14: Customer loyalty		x		Trend fluctuation
KPI 15: Increase of sales	x			Growth of sales
KPI 16: Sales profitability	x			Wide net profit margin
<i>Financial perspective</i>				
KPI 17: Collections	x			Collections of receivables - high level
KPI 18: Payment	x			High level of liquidity
KPI 19: Income structure	x			The growing share of services' revenues
KPI 20: Liabilities structure		x		Fixed costs increased
KPI 21: Financial result	x			Profit trend growth

Most of the identified key performance indicators (17 from 21) fully confirm that company has improved its operations in the observed three-year period. In such a way, the hypothesis set in the plan of the research was validated. On the other hand, only 4 key performance indicators signal that the integral model of strategic management did not fully meet expectations (these indicators partially confirm the hypothesis).

Particularly conclusive proofs of successful functioning of integral model of strategic management are: (1) employee satisfaction; (2) compliance with standards ISO 9001:2008; (3) increased customer satisfaction; (3) financial result.

Employee satisfaction is one of the most important indicators in the integral model of strategic management. This importance is emphasized in all four elements that make the model. Concerning the first element (new product development) employees' role is mostly expressed through creativity, which is essential in the development of new products. The second element (TQM) involves active participation of employees at all levels in building quality management system. Also, one of essential principles of TQM is team work, which requires good interpersonal relations in the organization. Likewise, the TQM insists on intensive training and education of employees. The third element (brand management) relies on human factor too. In the fourth element (CRM) employees' role cannot be omitted. Finally, in BSC measurement system (embedded in integral model of strategic management) a specific perspective referring to measurement and monitoring of the results achieved in this area was developed. In the observed company, in which the model of strategic management was installed, employee satisfaction was assessed annually on the basis of a questionnaire. The questionnaire covered 87,1% of employees in 2011 and a year later 96,6% but in 2013 all employees completed it. Employee satisfaction increased from 8,96 in 2011 to 9,30 in 2013. High average grades of employees indicate that the company managed to create good conditions in the workplace, a good atmosphere at work, to motivate employees and encourage them to achieve the vision and goals of the company.

Compliance with international quality standards ISO 9001:2008 is expressed on the basis of quarterly internal audits of the quality system. According to internal audits reports, most of the non-conformities were recorded in 2011 and in the next two years the quality system of the company was greatly improved. In addition, it should be noted that out of total 12 internal audits, this system received the highest score (10) five times, four times it was graded "nine" and just three times by "eight". There were no scores lower than 8, and the average score in this period was 9,2.

Customer satisfaction, in this research, was measured through the questionnaires which included six important segments: a) retail offer; b) Internet sales offer; c) effectiveness in complaints resolving; d) the expertise of the sales staff and employees who are engaged in after-sales support; e) friendliness of the staff and

f) price. Customers evaluated each of the above segments from 1 (lowest satisfaction) to 5 (highest satisfaction). Questionnaires have shown that each year better results were reached. In 2011 grades were, on average, lowest (3,94). Customers were least satisfied with the price (3,30) and retail offer (3,54). On the other hand, they showed the highest level of satisfaction due to kindness of the staff. During the next year, customer satisfaction was significantly improved, as the average grade was 4,33. Compared to the previous year, in 2012 based on 5 out of 6 selected criteria the grades were improved. Thereby, the maximum increase rate was related to the Internet and retail sales. However, the best results were accomplished in 2013 (average grade even 4,57). According to customers' grades resolving complaints was further enhanced, professional customer support and kindness of the staff, too. Customers have even shown a higher degree of price satisfaction.

Finally, the results achieved in creativity perspective, quality perspective, brand perspective and consumer perspective are reflected in the financial performance or financial results. After the implementation of the integral model of strategic management, it was noticed that there were consistently increased revenues and expenditures. During the reporting period, revenues increased by 13,2% and expenditures by 12,6%. However, the achieved positive financial result considered in absolute amounts compared to the total turnover, as well as, in relation to the assets, does not show high profitability. For example, Return on Assets (ROA) in 2011 was only about 1,8%. This means that every 100 RSD of engaged assets made only 1,8 RSD profit. In the following year this indicator remained unchanged, but by the end of 2013 it reached the level of about 2%. Reviews of low profitability can be confirmed by the rate of net income (net income/sales revenue). This indicator, at the end of 2011 was only 0,72%, in the following year 0,82%, and at the end of 2013 it was 1,20%. Such low values indicate that only a small portion of sales revenue go into profit (the largest portion of sales is burdened with expenses, indicating a lower level of cost-effectiveness). Slightly different picture is obtained on the basis of the rate of Return on Equity (ROE). In 2011, this ratio stood at 10,2%, in the following year 10,8% and in 2013 at 14,2% which is quite high in comparison to the very successful companies. This indicator illustrates that the observed company with a relatively small capital runs a significant volume of turnover and makes profit (every 100 RSD of capital invested in 2013 makes 14 RSD of profit).

Based on such review, it can be concluded that the company is more successful after applying the integral model of strategic management. It should be noted that the model was implemented at a time when the global economy was not recovered from the deep recession. Economic conditions in Serbia were also very unfavorable. So, these good results cannot be attributed to random, or a positive effect of external factors, but primarily to internal factors of the company (efficient strategy, organizational solutions, innovation, flexibility, knowledge and energy of management and employees).

Conclusions

Regarding the relevant literature studied, it was found that among many modern management concepts there are a lot of similarities, which reveals the possibility of their interconnection. In this analysis, it was concluded that new product development management, total quality management then brand management and customer relationship management are theoretically compatible management paradigms that can be synthesized into a unique integral model of strategic management. In addition, measuring system based on balanced scorecard has been installed into this model, thus significantly contributing and expanding the frames of current literature on strategic management.

The primary purpose of integral model of strategic management is to make a positive impact on company performance. In this sense, the hypothesis in this research was defined, which was verified based on the experiment under real market conditions over the period of 2011-2013. Measurements showed that the integral model of strategic management is functional and influences the improvement of company performance.

Integral model of strategic management is a possible answer to the fragmentation of business concepts. It was not formed under the influence of one author or a business school, but as a result of many different cross-influences. It is complex in its structure (comprising four elements and a measuring system), but it is essentially simple, practical and applicable, which is confirmed by the experiment conducted with the company "Positive". It is similar in its characteristics to other business ideas, but at the same time different from them because it has its own, separate logic. It can be an evolution (bring continuous improvements), but can cause disruption in the balance of the company by introducing revolutionary changes. It is not elaborated in detail and does not offer ready-made solutions, but it has clear principles that represent a strategic roadmap for the company. In other words, its flexibility leaves enough space for the company to adapt it to its needs. To the authors' best knowledge, this study is the first to perform integral model of strategic management which contains four different, but compatible concepts with BSC as a measuring system. It contains creativity (new product development), process approach, administrative and organizational orderliness (TQM), emotions (through brand management) and respect for the consumer (through CRM). Ethical standards must necessarily be incorporated because it relies on the corporate culture. This study has discovered a number of areas where identified concepts overlap, but also complement and stimulate better results, thus identifying possible improvement fields and translating that potential into real synergy.

References

- [1] Abrahamsson, S., Hansson, J., & Isaksson, R. (2010) Integrated Management Systems - Advantages, Problems and Possibilities.

Conference paper - 13th Toulon-Verona Conference: Organizational Excellence in Service

- [2] Akao, Y. (1990) *Quality Function Deployment: Integrating Customer Requirements into Product Design*. Productivity Press
- [3] Anjard, R. P. (1998) Total Quality Management: Key Concepts. *Work Study*, 47 (7) 238-247
- [4] Bailetti, A. J., & Litva, P. F. (1995) Integrating Customer Requirements into Product Design. *Journal of Product Innovation Management*, 12 (1) 3-15
- [5] Bennett, L. M., & Kerr, M. A. (1996) A System Approach to the Implementation of Total Quality Management. *Total Quality Management*, 7 (6) 631-665
- [6] Boden, M. A. (1998) Creativity and Artificial Intelligence. *Artificial Intelligence*, 103 (1-2) 347-356
- [7] Chan, L. K., & Wu, M.-L. (2002) Quality Function Deployment: A Literature Review. *European Journal of Operational Research*, 143 (3) 463-497
- [8] Cooper, R. G. (1984) How New Product Strategies Impact on Performance. *Journal of Product Innovation Management*, 1 (1) 5-18
- [9] Cooper, R. G., & Edgett, S. J. (2010) Developing a Product Innovation and Technology Strategy for Your Business. *Research Technology Management*, 53 (3) 33-40
- [10] Crawford, M. C. (1972) Strategies for New Product Development. *Business Horizons*, 15 (6) 49-58
- [11] Dale, B. G., & Wilkinson, G. (1999) Integrated Management Systems - an Examination of the Concept and Theory. *The TQM Magazine*, 11 (2) 95-104
- [12] Davidson, H. (1997) *Even More Offensive Marketing - an exhilarating action guide to winning in business*. Penquin Books Ltd
- [13] de Chernatony, L., & McDonald, M. (1998) *Creating Powerful Brands in Consumer, Service and Industrial Markets* (2nd ed.) Butterworth Hainemann Limited
- [14] Fader, P. (2012) *Customer Centricity: Focus on the Right Customers for Strategic Advantage*. Wharton Digital Press
- [15] Garvin, D. (1988) *Managing Quality: The Strategic and Competitive Edge*. The Free Press
- [16] Gordon, I. (2001 September-October) CRM is Strategy, Not a Tactic. *Ivey Business Journal*

- [17] Griffin, A., & Hauser, J. R. (1993) The Voice of Customer". *Marketing Science*, 12 (1) 1-27
- [18] Grönroos, C. (1994) Quo Vadis, Marketing? Toward a Relationship Marketing Paradigm. *Journal of Marketing Management*, 10 (5) 347-360
- [19] Gummesson, E. (1999) *Total Relationship Marketing: Rethinking Marketing Management*. A Butterworth-Heinemann
- [20] Higgins, L. F. (1999) Applying Principles of Creativity Management to Marketing Research Efforts in High-Technology Markets. *Industrial Marketing Management*, 28 (3) 305-317
- [21] Holt, D. B. (2003) *Brands and Branding*. HBS Publishing
- [22] Injazz, C. J., & Popovich, K. (2003) Understanding Customer Relationship management (CRM): People, process and technology. *Business Process Management Journal*, 9 (5), 672-688
- [23] Irani, Z., Beskese, A., & Love, P. (2004) Total Quality Management and Corporate Culture: Constructs of Organisational Excellence. *Technovation* (24), 643-650
- [24] Iriana, R., & Buttle, F. (2006) Customer Relationship Management (CRM) System Implementations: An Assessment of Organisational Culture. *The International Journal of Knowledge, Culture and Change Management*, 6 (2) 137-147
- [25] Isaksen, S. G., & Akkerman, H. J. (2011) Creative Climate: A Leadership Lever for Innovation. *Journal of Creative Behaviour*, 45 (3) 161-187
- [26] Jorgensen, T. H., Mellando, M. D., & Remmen, A. (2006) Integrated Management Systems - Three Different Levels of Integration. *Journal of Cleaner Production*, 14 (8) 713-722
- [27] Kaplan, R. S., & Norton, D. P. (1992) The Balanced Scorecard - Measures That Drive Performance. *Harvard Business Review*, 70 (1) 71-79
- [28] Karapetrovic, S. (2003) Musings on Integrated Management Systems. *Measuring Business Excellence*, 7 (1) 4-13
- [29] Keller, K. L. (1997) *Strategic Brand Management - Building, Measuring and Managing Brand Equity* (1st ed.) Prentice Hall
- [30] Koen, P. A., Ajamian, G. M., Boyce, S., Clamen, A., Fisher, E., Fountoulakis, S., et al. (2004) Fuzzy Frond End: Effective Methods, Tools and Techniques. In P. Belliveau, A. Griffin, & S. Somermeyer, *The PDMA Toolbook for New Product Development*. New York: John Wiley & Sons
- [31] Ljubojević, Č. (2002) *Marketing usluga*. Novi Sad: Stylos
- [32] Miles, M. P., & Russell, G. R. (1997) ISO 14000 Total Quality Environmental Management: the Integration of Environmental Marketing,

- Total Quality Management and Corporate Environmental Policy. *Journal of Quality Management*, 2 (1) 151-167
- [33] Newell, F. (2000) *Loyalty.Com: Customer Relationship Management in the New Era of Internet Marketing*. McGraw Hill
- [34] Nikolić, V., & Nastasić, A. (2010) Organizational Culture as Significant Factor in Implementation of TQM - Experience in Serbian Economy. *International Journal for Quality Research*, 4 (1) 59-69
- [35] Payne, A., & Frow, P. (2005) A Strategic Framework for Customer Relationship Management. *Journal of Marketing*, 69, 167-176
- [36] Prajogo, D. I., & Sohal, A. S. (2006) The Relationship between Organization Strategy, Total Quality Management (TQM) and Organization Performance - the Mediating Role of TQM. *European Journal of Operational Research* (168) 35-50
- [37] Ries, A., & Trout, J. (1986) *Positioning - The Battle for Your Mind*. New York: McGraw Hill
- [38] Rigby, D. K., Reichheld, F. F., & Schefter, P. (2002) Avoid the Four Perils of CRM. *Harvard Business Review*, 80 (2) 101-109
- [39] Schonberger, R. J. (1992) Is Strategy Strategic: Impact of Total Quality Management on Strategy. *Academy of Management Executive*, 6 (3) 80-87
- [40] Schultz, D. E., & Barnes, B. E. (1999) *Strategic Brand Communication Campaigns*. Lincolnwood (Chicago), Illinois, USA: NTC Business Books
- [41] Urban, G. L. (2004) The Emerging Era of Customer Advocacy". *MIT Sloan Management Review*, 45 (2)
- [42] Yang, Y. (2010) The Construction to Brand Culture Based on Corporate Culture. *International Journal of Business Management*, 5 (4) 223-226
- [43] Zutchi, A., & Sohal, S. A. (2005) Integrated Management System: the Experience of Three Australian Organizations. *Journal of Manufacturing Technology Management*, 16 (2) 211-232

Qualification as a Success Factor in the Labor-Market: The Faculty-Specific Attributes of the Employment of the Budapest University of Technology and Economics Recent Graduates

Henrietta Finna, János Erdei

Department of Management and Corporate Economics (MVT) Budapest
University of Technology and Economics (BME), Magyar tudósok körútja 2,
H-1117 Budapest, Hungary, finna@mvt.bme.hu, erdei@mvt.bme.hu

Abstract: Due to the increasing expansion in higher education and the boom in the number of students, new challenges of employment have emerged. In the labor-market, different tendencies of fresh graduates can be highlighted, so it is essential to identify which success factors of the labor-market are relevant to the different training fields. A certain group of former BME students was chosen as a sample group and special variables, which can appear as important attributes of entering the labor-market, gender and field of studies were applied. We based our analysis on the BME career tracking survey that had been taken for 10 years among the graduates, with the purpose of examining main influencing factors of entering the labor-market and the correlation between these factors and further variances of qualification. We can declare that there are significant differences between the different fields of studies. Thus, in the center of our research is the detailed examination of the relationship between the factors of course duration and employment in the acquired professions in relation to the faculties. Despite the results of our correspondence maps painting a rosy picture of the situation for the recent graduates, due to the differences between the faculties, several tasks related to the qualitative aspects of the labor-market demand emerge for the higher education institutions and the students.

Keywords: engineering; recent graduates; qualification; labor-market indicators; correspondence map

1 Introduction

After the political transition in Hungary, the rapidly increasing output of higher education had considerable effects on national economic and social factors, such as: the increase in GDP per capita, rising tax income, acceleration of the increase in GDP due to income growth, lower level of corruption, increasing scientific performance, higher life expectancy, more active participation in politics, higher

commitment to social activity and higher level of social mobility [1]. At the same time, the labor-market has been changed, new challenges emerged, which demand great preparation of not only the recent graduates and their employers [2] — which we targeted to analyze — but also the whole society. To understand this, the factors which are in relation with the labor-market indicators and positively influence them should be recognized.

After the political transition the increasing expansion in higher education [3] and the boom in the number of students became typical; on the basis of the surveys in the Hungarian Central Statistical Office, between 1990 and 2005 the number of students in the higher educational system was quadrupled. The ratio of full-time students was also almost trebled, which incident was further enhanced by the Bologna Process in 2006. Meanwhile, the number of both the applicants and the students being accepted showed an increasing trend, which means that the young people did not meet such entrance barriers which could have kept them from entering higher education [4]. The appreciation of human resources value and the increase of investment in the human capital predicted that the possibility of claiming a higher social status and a greater social and financial honor are linked to higher qualification [5].

Since 1998, the employment rate among the graduates has been as high as 72-76% in Hungary. However, in the OECD member states the employment rate of people with higher education is on average 9% higher than the rate of people with secondary education; its ratio differs between countries. In Hungary the difference between the employment rates of the people with higher and secondary education is 12%, which is higher than the OECD average [6]. We must not lose sight of the fact that on the basis of the surveys published by the Hungarian Central Statistical Office, in the last two decades the number of job seekers (registered ones) increased by 64% (a bigger jump was observed in 2009), but what is even more annoying is that the number of the unemployed among the recent graduates had doubled; moreover, we face an even higher number¹ of unemployed highly qualified recent graduates nowadays. Therefore, the boom in the number of students in the higher education system has created a new situation on the labor-market on both the input and output sides as the unemployment of recent graduates has already appeared and it keeps increasing.

Taking notice of the above trends, it is necessary to identify the success factors of the labor-market which are relevant to the different training fields. These success factors provide information for the participants about the effectiveness of each training course in the higher education system and Lifelong Guidance (LLG) for young people.

¹ Rate of recent graduates among the unemployed entrants increased from 3% to 6% between 1998 and 2002, then to 9% in 2003; today it is 16%. [8]

For this, it is essential to give a picture of the Hungarian higher education system in brief pointing to the main indicators of employment, such as job search duration, employment in the acquired professions and income.

In the last years, among recent graduates besides the growing unemployment mentioned above, the average duration of job searching also increased. The following figures clearly illustrate the main indicators of the labor-market among recent graduates in the relevant training fields in Hungary. (See Figures 1, 2, 3)

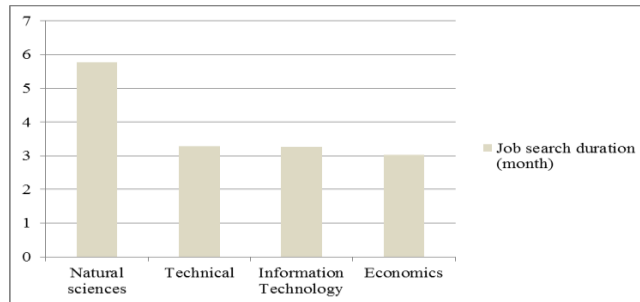


Figure 1

Job search duration among year 2007 graduates (N=2371 people), Source: [7]

Besides job search duration, professional qualifications and job matching are also important factors of the utilization of the university degree because the knowledge acquired becomes valuable only on a high level of compliance. In the training fields examined the Hungarian average values are:

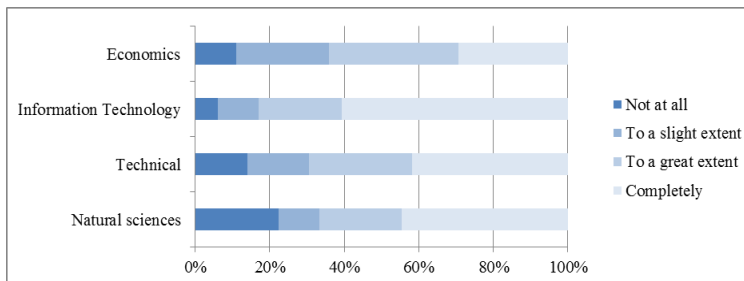


Figure 2

Year 2007 graduates employed in the acquired professions (N=4341 people), Source: [7]

The level of obtainable income on the labor-market can also be a result indicator of attaining a degree in relation to the training fields; see Figure 3 below:

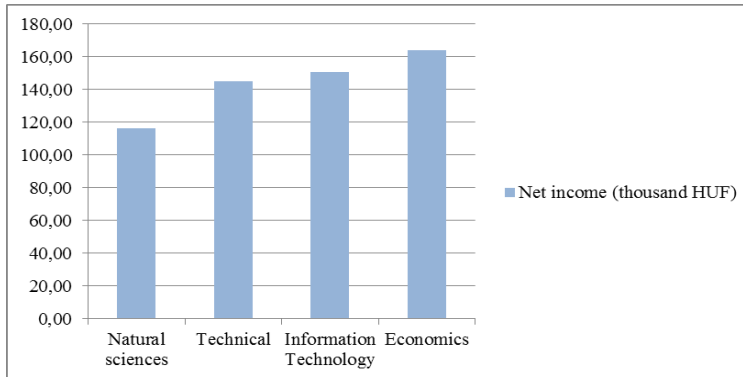


Figure 3

Amount of the average net income of year 2007 graduates (N=2691 people), Source: [7]

In the last years, in the private sector there was an increasing demand for professionals with certain qualifications and openness to employing recent graduates. In the survey published by the Institute for Economic and Enterprise Research of the Hungarian Chamber of Commerce and Industry focusing on the recent graduates of 2011, 42% of the examined companies already employed or planned to employ recent graduates within a period of one year [1]. As we are associates of a higher education institution (BME), for us it is essential to know about the chances of our BME recent graduates. At the BME there is a tradition of scientific analyzing and using results of different student surveys [9] [10]; we considered a certain group of former BME students appropriate for being a sample group, and we based our survey on a career tracking survey that had been taken for 10 years among the graduates of the university.

2 The Research

2.1 The Sample Group

Our research targeted to examine the BME recent graduates—who attained their first university degree there—as recent entrants in the labor-market. As we intended to introduce the real, average situation of the employment, we deliberately avoided the time and effects of the economic crisis. Thus, we specialized in surveying the groups of students who graduated between 2003-2007 in the training fields of engineering, science and economics.

Gender and field of studies² were chosen as the main variables influencing chances of getting a job among the BME graduates. We assume that these special variables can appear as important in the attributes of entering the labor-market of students from similar training fields of different higher education institutions as well.

During the survey period, using selected degree courses of the BME—full-time and correspondence university-level first degree courses—slightly more than 8600 students attained a degree. In 2005-2009 during the surveys of the career tracking system, the number of respondents was 1732 people, thus the average response rate was 20%. However, from statistical aspects it cannot be considered as a random sample; regarding its ratio and size the sample itself seems to be outstanding, and it assures a solid basis of our estimates and drawn consequences. As the statistical population is known, we examined whether—according to the variables gender and field of study—the sample can be considered representative. Certainly, as we could not guarantee perfect concordance, we produced statistical weight numbers associated with our observations, which reflect the ratios in the statistical population. We carried out weighting processes annually because during this period the number of economics students on the GTK had started to increase and the ratio of men to women changed; it was different from the already running engineering management degree course. For dependable annual results we produced statistical weight numbers on an annual basis. Thus, the sample can be considered representative, from the aspects of gender, field of study and the ratio of graduates per year, as well. As for the reliability of the sample, we faced another problem. In TTK the population, thus the size of the sample group, was too small. Regarding the whole sample, this faculty can be considered representative as well, but groupings—especially by several criteria—resulted in some cases to low sample numbers that would distort the sample indicators. Thus, we took TTK into account only when we managed to get comparable results and we made comparisons, mainly between the faculties on the basis of only one variable.

2.2 The Purpose and Methodology of Our Research

The present study gives an overview of the second phase of our research on BME recent graduates. Our purpose is to examine each influencing factor of entering the labor-market; furthermore, the correlation between certain factors and further variances were found. However, in our previous survey [11] —which is the basis

² Faculties we examined are the Faculty of Civil Engineering (ÉMK), the Faculty of Architecture (ÉPK), the Faculty of Economic and Social Sciences (GTK), the Faculty of Mechanical Engineering (GPK), the Faculty of Transportation Engineering and Vehicle Engineering (KJK), the Faculty of Natural Sciences (TTK), the Faculty of Chemical Technology and Biotechnology (VBK) and the Faculty of Electrical Engineering and Informatics (VIK).

of our present work—we emphasized the examination of basic tendencies that could be indicative of annual trends; there was missing analysis between certain elements. Thus, the identification of potential intervention points was also missing. Now, we intend to fill this gap with our present study. As for the sample we had, it was considered reasonable to examine the correlations between certain grouping variables and taking a job in the labor-market. For that purpose, in order to analyze association and correlation we chose certain criteria such as gender, field of study, status, job search channel, employment in the acquired professions, number of workplaces, job search duration, the position, job satisfaction, managerial perspective, income and the level of mobility.

In the given five-year period, studies were made with different coding systems, thus some factors became necessary to re-code so as to make them completely comparable. While applying Pearson's chi-squared test (χ^2) we found that a certain category did not contain sufficient elements, thus, according to professional criteria we had to merge some categories. We considered correlations in relation to the p-value, and in case we found correlations, we determined the closeness of them by Cramer's V.

However, the test of independence and Cramer's association coefficient describe the existence and the closeness of the relationship well; they are not able to represent the nature of the relationship. Thus, we extended our research by applying a multivariate exploratory method (correspondence analysis). This allowed us to establish the relationship between the categories of certain quality criteria; whether the increasing incidence of a certain category of criterion implies the increasing incidence of another category of criterion or vice versa. The method is an exploratory research; the main thing is that the rows and columns of the correspondence table are interpreted as points in a multi-dimensional space which points then are represented in a reduced two or three-dimensional space [12]. Depending on the situations of these points (categories of criteria) we can decide whether the belonging variables attract or repel each other.

3 The Most Important Results of the Basic Research

3.1 Gender, as a Grouping Variable

We highlighted the correlations of the gender because we found it relevant in relation to the social status, the job search channels, the job search duration, employment in the acquired professions, the leadership perspective, the position, the level of salary and income and the level of mobility.

It is important to record that from the aspect of gender the university faculties are not homogeneous, there are significant differences between the faculties and the degree courses. From this aspect, the BME is quite a “masculine” institution. Therefore, it is not surprising that in the given period the ratio of the male-graduates was 75%. We found more diversity in the genders in relation to the different faculties. The faculties of VIK, GPK and KJK are not popular among women; the ratio of them was below 10%. In the faculty of GPK we can see that the ratio of female-graduates is above 10%, which is mainly due to its product designer course; see Figure 4. The degree courses of the TTK are a little bit more popular among women; the ratio of them was 20%. As for engineering jobs, architecture, chemical engineering and biotechnology were the most attractive fields for women, also civil engineering was popular among them. At the faculty of VBK, slowly, the trend becomes the opposite as the ratio of women to men is near 2/3. At GTK the ratio of men to women is 50%.

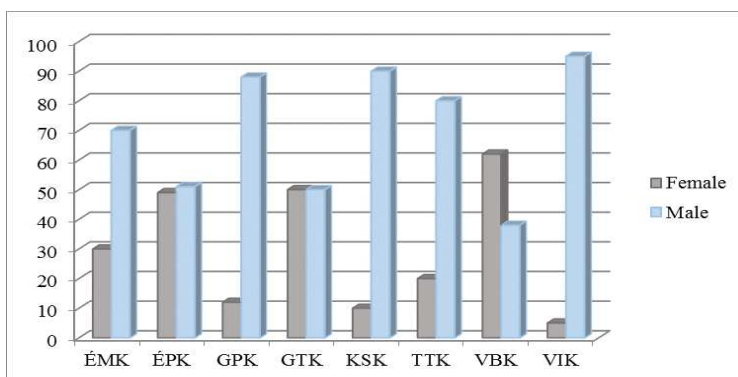


Figure 4

Ratio of men to women in relation to faculties (%)

On the basis of the studies relevant to this topic it can be concluded that for the salaries in relation to genders the determination of the differences became almost compulsory. Regarding the present survey, as for the monthly salaries, we face huge differences in the range of the smallest—some thousand Hungarian Forints—to the highest amounts such as some million Hungarian Forints as well. Thus, in order to examine correlations we had to create categories according to the amounts of salaries. Because of the standard deviation of the average salaries we applied a non-proportional scale; for the smaller amounts we applied narrow intervals and for the higher amounts we applied wide intervals.³

³ For comparability, by the official inflation data of The Central Bank of Hungary we converted the salaries in earlier years to 2009.

Figure 5 below illustrates the ratio of salaries of women to men. The figure shows the relative frequency of each salary category in relation to genders.

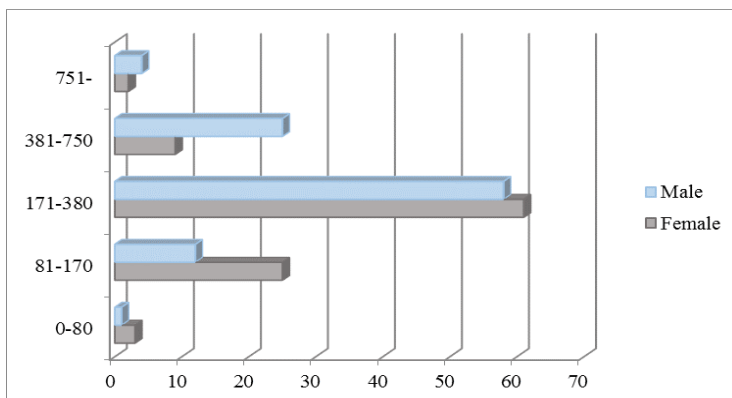


Figure 5
Average monthly salaries in relation to genders

It is obvious that until 89.2% of women have a monthly salary of a maximum of 380 thousand Hungarian Forints, only 10.8% of them are above this level; among men who take place above the level of salary mentioned this ratio is 30%. Women are more dominant in the categories of lower salary levels, demonstrating our assumption about horizontal segregation and, therefore, gender-based discrimination in pay.

In view of the fact that in relation to faculties there is huge heterogeneity in the ratio of men to women, the above difference can be originated from the difference between the salaries of each profession. We examined this difference in relation to faculties as well, which confirmed our previous assumptions. Two years after entry into employment, the gap between the salaries of men and women is already appreciable. Except for VBK, all the faculties' men have a higher income; see Figure 6. We found the smallest difference at VIK, but for the ÉMK-ÉPK graduates the amount of the difference is between 60 thousand to 80 thousand Hungarian Forints. The huge differences between the faculties are also illustrated below. During the given period the VIK graduates had the highest income, and then came the GTK graduates; finally, the VBK and ÉPK graduates, as well. (Because of the small size of that, while analyzing the results, we did not take TTK into account.) As for the trends in results, we found them to coincide with the self-declared net monthly salaries of the recent graduates [7], except the VIK graduates, who have almost a twice higher income than the average in the field of engineering. It reflects the outstanding positive esteem and the great demand for the VIK graduates in the labor-market.

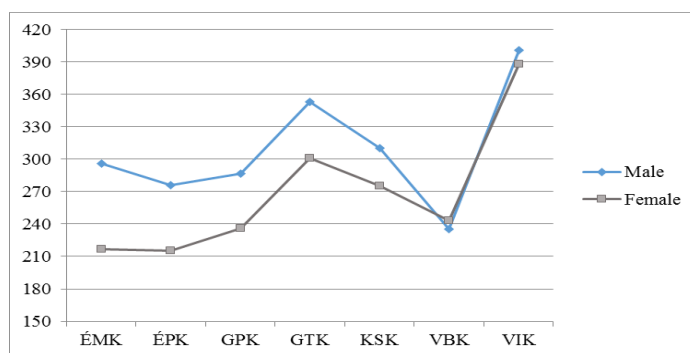


Figure 6

Average monthly salary in relation to faculties and gender (in thousand Hungarian Forints)

3.2 The Faculty, as a Grouping Variable

As for employment in the acquired professions, we presumed serious differences among the results of the different faculties. With Pearson's chi-squared test (χ^2) we demonstrated that a correlation exists; moreover, there is a modest correlation between employment in the acquired professions and the training field (faculty). Efficiency of employment in the acquired professions is seen in the figure below (employed in the acquired professions [yes], or not [no], or employment complies with the acquired professions only in certain aspects [partly] [see Figure 7]).

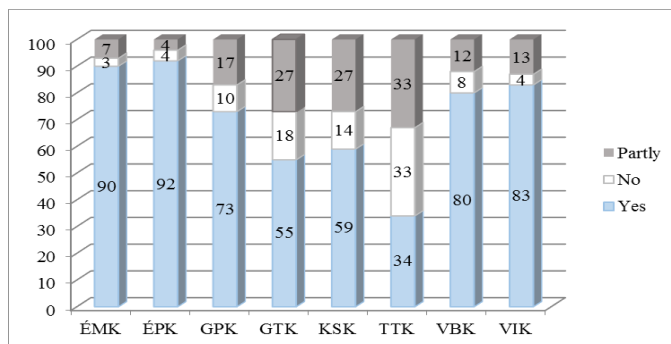


Figure 7

Employment in the acquired professions in relation to faculties (%)

The lowest proportion of those who could find work in the acquired professions is the TTK graduates; they are forced to be employed in professions partly other than those for which they are qualified. For them, the ratio of being employed in professions other than those for which they were qualified is 33%. We did not face such a high ratio at any other faculties; moreover, this proportion is higher than

the Hungarian average (14.4%) [7]. The highest proportions of those who could find work in the acquired professions are the ÉMK-ÉPK graduates; their ratio is above 90%. The VIK and also the VBK graduates—with their volume limited—also have a relatively high proportion. The GPK and KJK graduates hold the middle ground, and beside the TTK graduates, the GTK graduates have the worst results with their ratio of 18%— which is 7% higher than the Hungarian average [7]. From this aspect, creating jobs which promote functional flexibility and where the recent graduates can utilize their various competencies is worth considering; hence, it would be desirable to establish the so-called post-Fordist model [13].

Employment in the acquired professions forecasted positions potentially available, but we considered it to be important to examine positions in relation to the faculties. In this case, testing of the relation showed one of the strongest associations. The ratio of each position in relation to the faculties is shown in Figure 8, below:

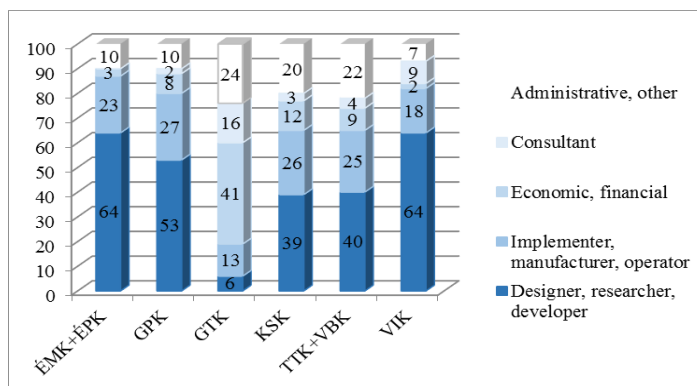


Figure 8
Types of jobs in relation to faculties (%)

At designer, researcher and developer positions the VIK, the ÉMK, and ÉPK graduates seem to be very good; in these jobs 60% of them are employed. The GPK graduates come second, followed by the KJK, the VBK and TTK graduates. In the last three groups it is typical to have a constructor, manufacturer or operator position, while as for the GTK, graduates are rather employed in economics, finance, commerce, sales representative, administrator and other similar positions. This category also includes the highest number of consulting jobs in which the VIK graduates are also employed, but in a smaller proportion. In administration jobs we found a high number of TTK, VBK and KJK graduates; in these jobs VIK graduates are employed in the smallest proportion.

4 The Results of the Supplementary Study: Introducing the Differences between the Faculties

According to the examinations introduced above, we can declare that in relation to certain criteria there are significant differences between the faculties. Thus, in the center of our research there is the detailed examination of the relationship between the factors of course duration and employment in the acquired professions in relation to the faculties. Due to the lower level of vocational maturity and so-called post-adolescence, one of the most frequently mentioned mistakes of the credit system—which is famous for its flexibility—is the lower level of student motivation in fulfilling course requirements [14]. These trends result in extended course duration. Furthermore, the credit system functions as an escape route from entering the labor-market. [15]

4.1 Associations of the Course Duration

As for the course duration, we could use only a part of our database because respondents were asked about the starting year of higher education only from 2007. Without taking college courses into account, we had a sample of 1026 people. According to the time spent between the starting and ending years of the courses, regarding the five-year university courses we created four groups. Hence, we organized the samples into the groups of the five-year long, the six, the seven and the eight-year or longer courses. Taking a test of independence between the grouping variable of faculties and course duration, the result of Pearson's chi-squared test (χ^2) was 181.4, and the p-value was 0.000, which shows that in relation to the course duration there is a significant difference between the faculties. This is a moderate strong association, where the Cramer's V-value is 0.243. Taking a correspondence analysis, we found the following results (see Figure 9).

On the map numbers 1—4 mean the categories of course duration: 1=five years, 2=six years, 3=seven years and 4=eight years or more. The rows of the initial contingency table contain the faculties, and the columns contain the categories of course duration⁴. The two-dimensional presentation reflects 96.26% of the total inertia (nth part of the calculated χ^2 -value); thus it represents the complete table well.

⁴ Results for the TTK have not been considered because of its small amount of elements in the group. We rather indicated it as additional information only.

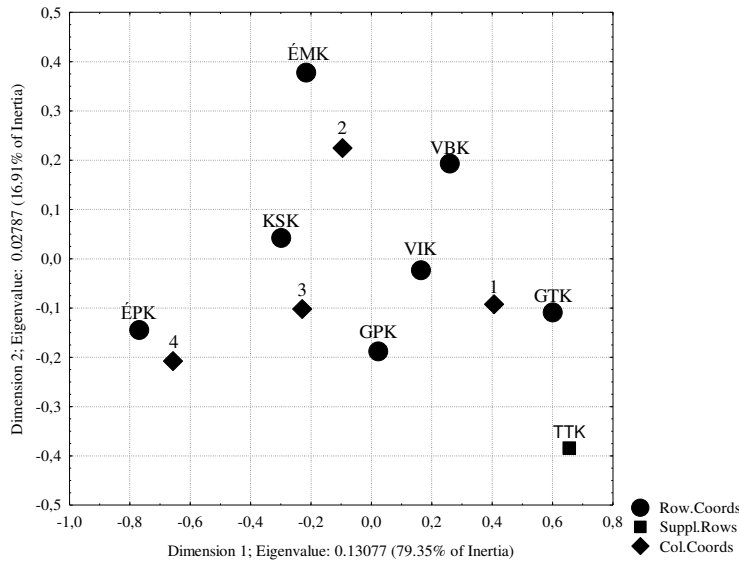


Figure 9

Correspondence map of the relationship between course duration and faculties

The values of the quality show that for both the row and column categories, almost all points are represented well by the first two principal axes and the points are close to the plane that is stretched by the two principal axes. Regarding the faculties, the quality value of the KJK only, and regarding the time, the quality value of the category 3 (course duration is seven years) is below 90% and these points are farther from the plane. According to the inertia, the standard deviation of row values is due to the difference between the ÉMK and GTK graduates, while the standard deviation of the column values is due to the difference between the categories of standard course duration and three-year longer course duration. Interpretation of the first principal axis is based on the difference between ÉMK and GTK graduates, with coordinates with opposite signs, while from the aspect of rows the two endpoints of the second principal axis are the GPK and ÉPK. Regarding the column coordinates, the two endpoints of the first principal axis are the categories of the standard course duration and the significantly prolonged course duration, while the second principal axis makes a difference between the categories of the one-year longer course duration and the three or more years longer course duration.

Figure 9 shows that GTK (and also TTK) is closer to column category 1 and ÉMK is closer to column category 4. On this basis, we found that among respondents most of the GTK graduates finished their studies on time, while the row category of graduates of architecture is close to the column category of the three-year longer course duration. Other faculties bridge the two poles. The VBK, VIK and

GPK graduates finish their studies usually on time or one year later and the ÉPK graduates finish usually one year later, while the KJK graduates attain their degrees one or two years later.

Examining the row profiles (see Figure 10) we can understand the difference between the faculties. The figure represents the relative frequency of the categories on the same Y-axis according to the faculties, from the left to the right, appropriate to the four time categories. 66.67% of the GTK graduates finished their studies in five years. As for the engineering faculties, only the relative majority finished their studies on time. 43-46% of the VIK, VBK and GPK graduates finished their studies in five years. ÉMK graduates usually delay one year, and 54% of them finish their studies in six years, which is true also for the KJK graduates, although for them the course duration is more variable and the maximum ratio is only 38%. Regarding the course duration, ÉPK can be considered specific, as 36% of the graduates delay at least three or more years. Less than 10% of ÉMK graduates finish their studies in five years; however, another 35% finish in six years; these two groups taken together do not cover 50%. (For the sake of completeness, we also represented TTK, but we must note that due to the small size of the sample group the only consequence which we can draw is that the vast majority of TTK graduates finished their studies on time, and the results of any further distribution is uncertain.)

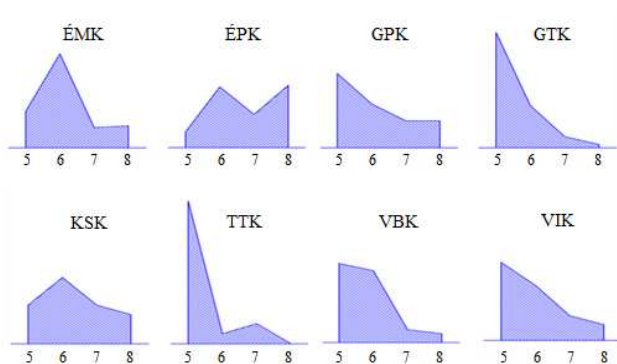


Figure 10

Relative frequency of course duration categories in relation to faculties (in year[s])

However, compared to the standard course duration most graduates delayed in finishing their studies, and the vast majority (72.2%) of them attained their degrees with only one year of delay. In the given period the average course duration for BME graduates was in 6.1 years with relatively high standard deviation, which is 1.4 years. The average course duration was 5.3-5.5 years for the TTK and GTK graduates, while an average student of architecture attained his or her degree only 7.1 years after registration at the university.

These outstanding results raise the question whether there is an association between labor-market facilities and the course duration for ÉPK-ÉMK graduates. Considering the difficulties of entering the labor-market, do they extend their course duration voluntarily? Or do they delay in completing their studies due to working while studying? If our first assumption is true, then finding a job should be the most difficult—thus job search duration should be the longest—for the ÉPK graduates. As for employment in the acquired professions, we already found that 90-92% of the ÉPK and ÉMK graduates are employed in their acquired professions (see Figure 7). As for the job search duration, we can see that ÉPK graduates can find a job easier than the average fresh graduate. Hence, our presumption that the increase in the course duration is influenced by the students' own decisions is not proved. However, the reason for it is due to the structure of the course itself; presently it is not targeted to be analyzed in this study.

However, for the other training fields we did not find outstanding results; it is worth examining the employment rates from faculty-specific and gender-specific aspects.

Examining the job search process of the graduates during the university years in relation to faculties, we can determine two groups. 60% or a higher ratio of the ÉPK, ÉMK, GTK, TTK and VIK graduates found a job during the university years, while for the GPK, KJK, VBK graduates it is below 50%. This ratio is the smallest for the VBK graduates with 32.4%.

We considered it important to examine the employment rate in relation to gender, as well. Taking the employment during the university years into account (calculated with 0-month of job search duration), the results of average job search durations for the graduates of faculties—in relation to gender—are the followings:

Job search duration is the shortest for the faculties of ÉMK and ÉPK, even shorter than the average job search duration of 1.3 months of the IT engineering graduates, which is one of the most popular jobs in demand. Meanwhile, the job search duration of the GTK and also TTK graduates is longer than the average, which means that among the given faculties, they do not find their jobs in the shortest time. Hence, it is not demonstrated that the course duration is not influenced by the chance of being employed.

Except for VIK, it is typical for every faculty that the job search duration is longer for women than for men. We can see the largest difference at the faculty of GPK partly due to its product designer course. For the graduates of this course the job search duration is 2.6 months longer than for the graduates of other courses; moreover, for this course we found the largest difference in job search duration (1.7 months) in relation to genders. As nearly 70% of female GPK students go to the product designer course, it significantly increases the average job search duration of women at the level of the faculty.

Examining only those students who started to search for a job after graduation, we can say that ÉMK and ÉPK graduates found their jobs in the shortest period of time, but the average job search duration for them is 2.6-2.8 months. As for the graduates of engineering, with its nearly 4.6 months, the job search duration is the longest for the VBK graduates. Surprisingly, for VIK graduates, with its 4.0 months, the job search duration is not much shorter. Similarly, the job search duration is 4.6 months for GTK graduates, too.

In conclusion, we can declare that the chances for entering the labor-market overall show good results. 57% of the BME graduates had worked before they attained their degrees, 26.8% became employed within three months after graduation (together, it is 83.8%) and within six months after graduation 94.2% of BME graduates were employed. Among BME graduates, the graduates of ÉMK and ÉPK find a job in the shortest period of time, and VBK graduates have the longest job search duration. However, most GTK and VIK graduates start working during the university years, and those who find or search for jobs after graduation typically face a job search duration of longer than the average.

4.2 Associations of the Employment in the Acquired Professions

We examined the chances of graduates for being employed in the acquired professions in relation to faculties, as well. We can declare that 77.8% of the recent graduates are employed in the acquired professions, 14.3% of them are employed partly in the acquired professions and 7.9% of them are employed in professions other than those for which they were qualified. In relation to the different faculties, there can be large differences among those who leave their professions. Pearson's chi-squared test for independence (χ^2) rejects the independence between the two criteria because the $\chi^2 = 180.5$, the p-value = 0.000 and Cramer's V = 0.237.

For a more detailed result, we applied a correspondence analysis to examine the difference (see Figure 11) and we obtained the correspondence map; see below. We can see that leaving the profession is the least typical for the engineering faculties; except for KJK; the results take place around the "yes" answer. More than 70% of these graduates are employed in their acquired professions. 59.6% of KJK graduates are also employed in their acquired professions, but compared to the engineering faculties here the ratio of "employed partly in the acquired profession" answer is relatively high with its 26.0%. The TTK and GTK graduates are the least employed in their acquired professions; it is typical mainly for the TTK graduates, and from this aspect, the GTK is rather a transition faculty between the TTK and the engineering faculties. For the TTK, 33.3% of the graduates were employed in the acquired professions, while for GTK this ratio was 50.4%.

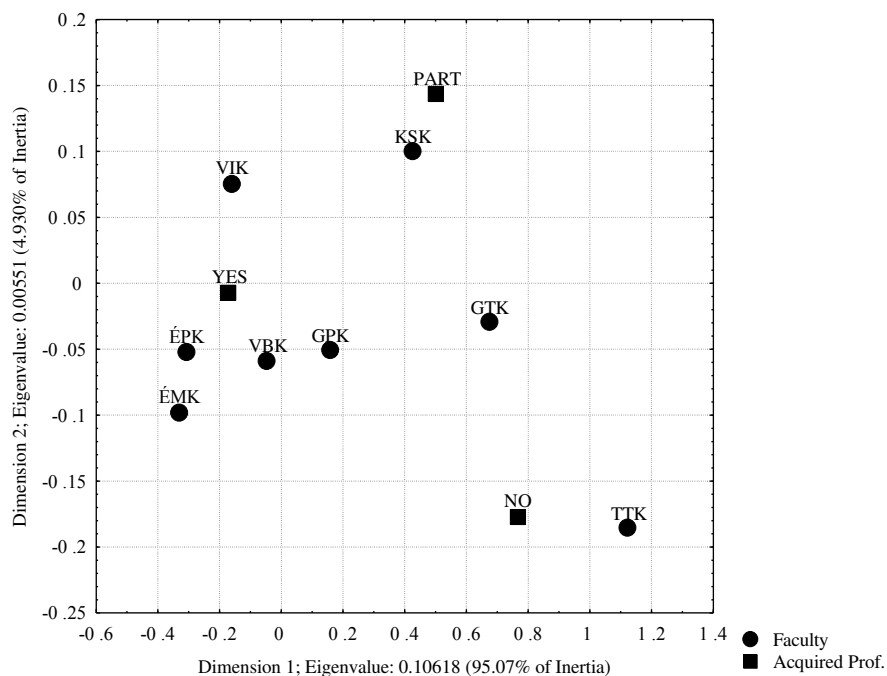


Figure 11

Correspondence map of the relationship between employment in the acquired professions and faculties

Conclusions

In order to provide the most important conclusions—like in the study of [16]—we considered it important to manage the results we collected, aggregated, together with the specific data of release. To this end, having regard to the employment of all graduates, we compared the relationship between the job search duration and payment, and the number of graduates in relation to faculties. The sizes of the faculties are proportional to the number of respondents at the certain faculties, where the students graduated from; their numbers are presented by the sizes of the circles, see Figure 12. The two types of the job search process (during the university years/after graduation) are presented separately. On the 0-value of the employment time axis we can see those circles which represent the graduates who became employed during the university years. The upper row of data indicates the job search durations after graduation, in relation to their faculties. The broken line indicates the average values with regard to the whole university.

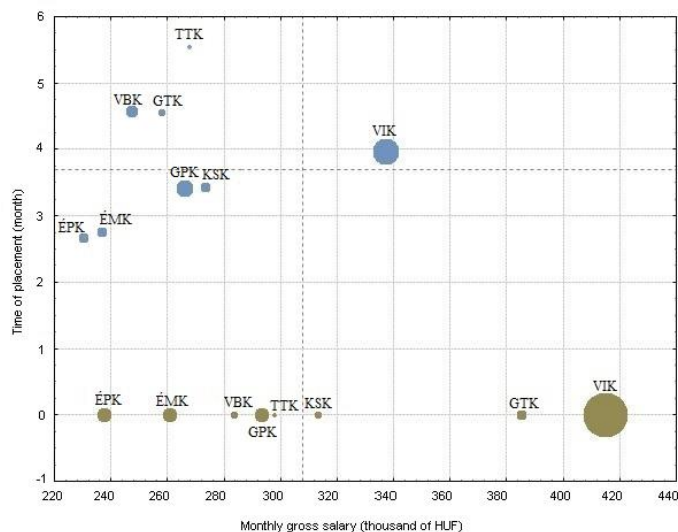


Figure 12

Differences between the faculties, in relation to job search duration and average payment

Examining the job search durations respectively (during the university years/after graduation), we can see that, except for two faculties, graduates need at least 3.5-4.5 months to find a job. Furthermore, the recent graduates of TTK belong to a single category because in the case they do not find a job during the university years, for them the job search duration has been extended to six months and it can be a relevant problem to be employed in professions other than those for which they were qualified. If beside the above-mentioned facts we also examine the payment, we can see that the salaries keep decreasing in all training fields in case the graduates find their jobs after graduation. At this stage, we must highlight the “loss” of the recent graduates of the financially appreciated faculties of VIK and GTK.

ÉPK and ÉMK graduates are in a special situation. However, for them among all the faculties the job search duration is the shortest—most of the students find a job during the university years—and they have the lowest level of salary. By contrast, in the labor-market, we can find a higher number of them, which results—from the aspect of labor-market efficiency—in a less favorable situation.

As for the labor-market success among the faculties, VBK graduates are in one of the worst situations because beside GTK graduates, they have the longest job search duration—approximately as long as it is for the ÉMK-ÉPK graduates—and also the lowest level of income. Only a low percentage of them can find a job during the university years and after graduation for them it is harder to be employed in their acquired professions. Regarding the training fields of BME, in

this case we face a female-dominated profession, which also can provide an explanation for the unfavorable ratios. Hence, for this field, raising the number of graduates is not reasonable.

Regarding both the employment in the acquired professions and the obtainable income, the VIK recent graduates have the biggest labor-market success. For them it is typical to find a job during the university years, but if they fail to do so, it has a negative influence on their job search duration and also their obtainable income. For them, besides the high level of professional standards—confirmed by also the employer organization or association—the so-called soft skills are also very important because these competencies make them truly valuable in the labor-market. Hence, for this field, the highest number of graduates produced is justified from every aspect; moreover, increasing the number of them could be a target for the future.

GPK and KJK graduates belong to the middle field from every aspect, with their employment rates above the national average and near the BME's university average. Finding a job during the university years is similar to VIK graduates, but for them, finding a job only after graduation does not have such a negative influence on their obtainable income. For them, BME as a brand name is very important in the labor-market and the educational institution itself is considered to be of high prestige. For the faculty of GPK, the number of graduates produced is a multiple of the number of KJK graduates, which is not justified by the examined labor-market ratios. For the KJK graduates it can be advantageous to increase the number of graduates.

For GTK graduates the picture is not that clear. Beside the obtainable income—which is higher than the national and also the university average—for them it is also important to find a job during the university years. If they do so, they are usually employed at companies of high prestige, mainly in their acquired professions, while if they start to search for a job only after graduation, similar to VBK graduates, the loss of time can result in failure, which can lead to leaving the profession. As for the number of graduates produced, on the basis of the great demand for GTK graduates and labor-market recognition, we can say that it would be justified to increase the number of GTK graduates to the similar number of VIK graduates, if business relationships were strengthened during the course. In lack of that, the recent graduates of this faculty can meet heavy losses.

For the TTK, the above-mentioned favorable trends are not typical at all. Job search duration is longer, and the obtainable income is lower than the university average. In order to increase the number of graduates, there should be even more radical changes in this field. True solutions would be to boost up labor-market demand and to promote professions in the field of natural sciences.

However, the results—which are presented by the employment rates—paint a rosy picture of the situation for the recent graduates of BME, and the differences between the faculties point to several other things, which have to be done by both

the higher education institutions and the students. Although the quantitative ratio of demand to supply seems to be appropriate, we mustn't forget about the qualitative aspects of the labor-market demand.

As for their own competencies, the self-images of recent graduates reflect a high level of satisfaction; they consider the professional usage of the internet, the self-expression in writing and meticulous work their three strongest competencies [17]. Further important competencies are the ability to study, to work in a team and self-instruction. As for their needs, the employers' side reflects a different opinion. For them, meticulous work, autonomy at work and heavy workloads are the most important competencies, in addition to the ability to work in a team, to have full theoretical knowledge and professional proficiency, ability to study, self-instruction and the ability to achieve the goals set [18]. Conversely, on the list of the least important competencies we can find proficiency in social issues, entrepreneurship and self-expression in writing. However, we can discover partial overlap between the two lists; responding to the employers' needs requires new formal and informal/non-formal developments [19] during the university courses.

References

- [1] Z. Várhalmi, L. Tóth, Recent Graduates in the Competitive Sector – 2011, MKIK GVI, Budapest, 2012, http://www.gvi.hu/data/papers/diploma_2011_osszefoglalo_120130_.pdf
- [2] K. Pádár, Innovative Recruitment of High Potentials: The Potential Benefits of Organising Student Competitions: Results of a Cross-National Study, *International Journal of Sales, Retailing, & Marketing*, 2(1), 34-49, 2013
- [3] Z. E. Tóth, T. Jónás, Enhancing Student Satisfaction Based on Course Evaluations at the Budapest University of Technology and Economics, Paper B11, *Acta Polytechnica Hungarica*, 11(6) 18, 2014
- [4] M. Szemerszki, Students in a Period of Mass Production, *Educatio*, Budapest, 4, 749-751, 2006
- [5] I. Polónyi, Employability, Over qualification, *Bologna*, *Educatio*, 3, 388-390, 2010
- [6] Z. Várhalmi, A. Czibik, B. Dörgö, Mobility and Employment of Recent Graduates (of technical, information technology and economic sciences) in the business sector, 2011, http://www.felvi.hu/pub_bin/dload/DPR_kotet_frissdiplomasok2011/10_varhalmi_czibik_dorgo.pdf
- [7] Educatio Public Services Nonprofit LLC., Tracking Graduate's Careers, 2010, Labor Market Features of Graduates of 2007, Research report, 2010, http://www.felvi.hu/pub_bin/dload/diplomas_kutatas2010/DPR_diplomas_kutatasi_jelentes.pdf

- [8] Hungarian Central Statistical Office, Dissemination database, www.ksh.hu, 2012
- [9] Z. E. Tóth, T. Jónás, R. Bérces, B. Bedzsula, Course Evaluation by Importance-Performance Analysis and Improving Actions at the Budapest University of Technology and Economics, *International Journal of Quality and Service Sciences*, 5(1), 66-85, 2013
- [10] B. Bedzsula, R. Bérces, Collecting, Analyzing and Application Opportunities of Student's Opinion for Improving Quality in some BME Courses, In: Topár J. (ed.), *Relevant issues in engineering management*, Technical Publishing House Ltd., Budapest, 2012, 153-168
- [11] H. Finna, Enhancing Employment and Motivation Opportunities of Recent Graduates with the Help of Atypical Solutions, In: Topár J. (ed.), *Relevant issues in engineering management*, Technical Publishing House Ltd., Budapest, 2012, 243-259
- [12] O. Hajdu, *Multivariable Statistical Calculations*, Hungarian Central Statistical Office, Budapest, 2003
- [13] P. Somlai, *Toward Adulthood*, presentation, MTA, Budapest, 2006, http://www.szociologia.hu/dynamic/SomlaiP_tanulmany.pdf
- [14] Gy. Vikár, *Crises of Youth*, Animula, Budapest, 1999
- [15] J. Salamon, *Psychology of Intellectual Development*, Gondolat Kiadó, Budapest, 1983
- [16] Educatio Public Services Nonprofit LLC., *Tracking Integration of Polity Databases, Research report*, Budapest, 2013, http://www.felvi.hu/pub_bin/dload/allamig_adatbazisok_diplomas_palyakovetesi_celu_integracioja_gyorsjelentes/Adatintegracio_gyorsjelentes_20140224_vegleges.pdf
- [17] Z. Várhalmi, L. Tóth, *Recent Graduates in the Competitive Sector – 2011*, MKIK GVI, Budapest, 2012, http://www.gvi.hu/data/papers/diploma_2011_osszefoglalo_120130_.pdf
- [18] E. Daruka, *Analyzing Competencies in Talent Management*, In: Topár J. (ed.), *Relevant issues in engineering management*, Technical Publishing House Ltd., Budapest, 2012, 281-295
- [19] Á. Szeghegyi, V. Lambert (Szoboszlai), J. Velencei: *Informal Post-Experiential Learning*, *Acta Polytechnica Hungarica*, Vol. 11, Issue 4, pp. 241-252, Budapest, 2014

Genetic Algorithm for Multi-Criteria Optimization of Multi-Depots Pick-up and Delivery Problems with Time Windows and Multi-Vehicles

Essia Ben Alaïa^{1,2}, Imen Harbaoui Dridi², Hanen Bouchriha², Pierre Borne¹

¹ CRISTAL : Research center in Computer Science, Signal and Automatic Control of Lille, UMR 9189, Central School of Lille (EC-Lille)
Cité Scientifique, 59651 Villeneuve d'Ascq, France
essia.benalaia@enit.rnu.tn, pierre.borne@ec-lille.fr

² LACCS : Laboratory of Analysis, Design and Control Systems, LR11ES20, National School of Engineers of Tunis (ENIT), University of Tunis El Manar, BP 37, 1002 Tunis Belvédère, Tunisia
imen.harbaoui@issatkr.rnu.tn, hanen_bouchriha@enit.rnu.tn

Abstract: In this paper, multi-vehicles, multi-depots pick-up and delivery problems with time windows (m-MDPDPTW) is presented as a multi-criteria optimization problem. The m-MDPDPTW is a variant of pick-up and delivery problem (PDP) and a challenging problem in the field of vehicle routing problem (VRP). The aim is to discover a set of satisfying solutions (routes) minimizing total travel distance, total tardiness time and the total number of vehicles. These routes satisfy transportation requests without contravening any of the instance specific constraints (precedence, capacity and time window constraints). In our problem each request is transported by one of the vehicles between paired pick-up and delivery locations. Such that, the depot does not retain the goods. In this paper, we assume that all vehicles have the same capacity and depart from and return to the same depot. The new encoding and structure algorithm on which this contribution is based uses a genetic algorithm, a selection process using ranking with several Pareto fronts and an elitist selection strategy for replacement. An improved encoding chromosome path representation is given to simulate the process of evolution using several types of populations in different sizes. The performance of the new algorithm is tested on data sets instances of Li & Lim's PDPTW benchmark problems. The results indicate that the proposed algorithm gives good results.

Keywords: multi-depots pick-up and delivery problem with time window; genetic algorithm; Pareto dominance; multi-objective optimization

1 Introduction

The general pick-up and delivery problem (GPDP) has received attention by many researchers in the last decade. This interest is due in part to its practical importance. The GPDP principle is to construct a set of routes in order to satisfy transportation requests. Each transportation request specifies the size of the load to be transported, the origin and the destination locations. Each load must be transported by one vehicle without any transshipment at other locations [1].

Extensive studies of routing problems are special cases of the PDP. The vehicle routing problem (VRP) is a PDP in which either all origins or all destinations are located at the depot [2]. In this case, all goods are transported between the depot and nodes. The problem is denoted vehicle routing with pick-ups and delivery (VRPPD). However, the well-known dial a ride problem (DARP) can be considered a PDP in which the loads to be transported represent people, and all load sizes are equal to one [3].

In this paper, we study a variant of PDP that is multi-vehicles, multi-Depots, pick-up and delivery problems with time windows (m-MDPDPTW) where paired pick-up and delivery locations are considered. Such that, the depot does not contain the goods. Even for a small problem size, this problem is NP-hard and difficult to solve its optimality, using exact methods [4].

This paper is focused on meta-heuristic techniques to solve multiple criteria problem optimally and is organized as follows: A brief literature review of the MDPDPTW is introduced in Section 2. In Section 3, we define our problem and we construct the mathematical model of m-MDPDPTW. The multi-objective problem, especially the Pareto method, is presented in Section 4. Section 5, proposes our genetic algorithm (GA) for solving a m-MDPDPTW problem to minimize the total travel distance, the total tardiness time and the number of vehicles. The resulting algorithm behavior is analyzed and tested to give the best-known solutions in Section 6. Finally, a concluding part of this paper is presented.

2 Literature Review

In our survey of the literature, we focus primarily on the PDPTW problem. Finally, we present the multi-objective existing algorithms.

2.1 Pick-up and Delivery Problem with Time Windows (PDPTW)

For a review of the PDP and its variants, the reader is referred to [1] and [5]. Considering PDPTW problem there is an abundant body of research, and several heuristic and metaheuristic approaches that have been designed. Traditionally,

heuristics run faster than metaheuristic methods, whereas metaheuristic usually outperforms simple heuristics with respect to solution quality [6]. Authors in [7], [8-10] presented various insertion-based heuristics to solve the PDPTW. Tabu search heuristics have been developed for PDPTW in [11] and [12]. Simulated annealing, genetic algorithm, adaptive large neighborhood search heuristic, and variable neighborhood search heuristic for solving the PDPTW are designed in [13-16]. A genetic algorithm and tabu search method for a special simultaneous PDPTW are proposed in [17].

2.2 Multi-Depots Problems

There are many evolutionary approaches for the MDVRP. Ombuki-Berman and Hanshar [18] used GA for MDVRP and introduced a mutation operator that targets the depot assignment to “borderline” customers, which are close to several depots. An algorithm named FLGA to solve VRP with multiple depots, customers and products is presented in [19]. The authors use the combination of GA search and fuzzy logic techniques to adjust the crossover and mutation rate. An interesting solution to the MDVRP using GA is found in [20], the proposed technique is composed of three phases. Firstly, they consider a regrouping phase then, a routing phase using Clarke and Wright saving method, and finally a scheduled phase. A large classification of published papers with more than 70 references involving order-first, split second methods is proposed for the MDVRP in [21]. However, a solution to the VRP problem using heuristics methods is proposed by Nagy [22] to solve simultaneous VRPPD for single and multiple depots. Finally, Wang [23] designed a new genetic algorithm for MDVRPTW with multi-type vehicles limits.

2.3 Multi-criteria Optimization Problem

Many research works dealing with evolutionary algorithms have focused on multi-objective algorithms. Several algorithms structures and methods have been proposed in [24]. There are those named “aggregated methods”, which bring the multi-objective problem into a single objective problem [25]. In addition, there is a class mainly based on a research process which deals with objectives separately. There are no aggregated and no Pareto strategy illustrated in the Vector Evaluated Genetic Algorithm (VEGA). Another way is explored in literature to increase both the quality and diversity of the solutions returned by the dominance Pareto concept. It aims to support research that satisfies all the possible objectives [26-28]. Zinflou proposed, in [29], a new Pareto generic algorithm, called GISMOO, which hybridizes genetic algorithm and artificial immune systems. Several recent multi-objective algorithms were inspired either by Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) or by Strength Pareto Evolutionary Algorithm 2 (SPEA2). Those algorithms use an elitist selection strategy for replacement. This elitism helps in achieving better convergence: the best solutions (e.g. non

dominated solutions) are kept either in the population itself or in a separate archive. In NSGA-II algorithm, the best solutions kept participate in the reproduction process which guides the exploration of the search space towards interesting areas [30, 31]. But, Strength Pareto Evolutionary Algorithm 2 (SPEA2) [32], preserves elitism by using an archive of non-dominated solutions, which does not necessarily take part in reproduction. A new multi-objective adaptive GA with multiple Pareto fronts called “aGAME” using multi-Pareto-ranking was proposed by Rudolph and al. in [33]. In their algorithm, another adaptive mechanism is introduced in order to improve both performance and the selection probabilities of non-dominated individuals and the mutation rate varies during the evolutionary process. For detailed information about other multi-objective algorithms readers are encouraged to refer to [34] and [35].

3 Problem Formulation

3.1 Problem Variants

The parameters of our problem are represented by the following variants:

L : Set of depots, $\{1, \dots, dep\}$;

H : Set of nodes (pick-up and delivery), $\{1, 2, \dots, n\}$;

H^+ : Sets of pick-up nodes, $\{1, \dots, (n/2)\}$;

H^- : Sets of delivery nodes, $\{1, \dots, (n/2)\}$;

H_c : Set of couples: delivery and pickup, $\{1, \dots, (n/2)\}$;

C_i : The couple (c_i, f_i) : the pick-up node (f_i) with its corresponding delivery node (c_i) , $\forall i \in \{1, \dots, (n/2)\}$;

V_m : Set of available vehicles from depot m (i.e. the maximum number of vehicles from depot m that can be used for pick-up and delivery), $\{V_1, \dots, V_{dep}\}$;

d_{ij} : Euclidean distance between node i and j ;

K : The total number of vehicles available for all the depots;

k : The number of the vehicles $\{1, \dots, |V_m|\}$;

q_i : Goods quantity request of the node i , (if $q_i < 0$ it is a delivery node else if $q_i > 0$ it is a pick-up node);

t_{ij}^k : Time taken by the vehicle k to travel from node i to node j ;

Q : The maximum capacity of a vehicle;

y_i^k : The load of vehicle k before leaving the node i ;

ET_i : The earliest time that node i can be serviced by a vehicle;

LT_i : The latest permitted time to leave node i ;

S_i : Service time at node i ;

A_i : Arrival time of the assigned vehicle at the node i ;

D_i : Departure time of the vehicle from the node i ;

W_i : Waiting time of the vehicle at node i ;

T_i : Tardiness time of the vehicle at node i ;

$Dist$: The maximum distance that can be covered by vehicles tours.

The mathematical programming formulation of m-MDPDPTW requires a decision variable, which models the sequence in which vehicle visits nodes. It's defined as follows:

$$x_{ij}^{mk} = \begin{cases} = 1 & \text{if vehicle } k \text{ originates from depot } m \text{ travel along arc } (i, j) \\ = 0 & \text{otherwise} \end{cases}$$

Taking into account the above variables and parameters, the problem can be formulated in the next section.

3.2 Mathematical Model

The m-MDPDPTW considered in this study aims to minimize total travel distance, total tardiness time and number of vehicles used. The objective function is formulated as:

$$f = \begin{cases} \sum_{m \in L} \sum_{k \in V_m} \sum_{i \in (H \cup m)} \sum_{j \in (H \cup m)} d_{ij} x_{ij}^{mk}, \\ \sum_{i \in (H \cup L)} \max(0, D_i - LT_i), \\ K \end{cases} \quad (1)$$

subject to:

❖ Maximum distance constraint is

$$\sum_{i \in L \cup H} \sum_{j \in L \cup H} d_{ij} x_{ij}^{mk} \leq Dist \quad (\forall m \in L \text{ and } k \in V_m) \quad (2)$$

❖ Each service node is visited only once by exactly one vehicle under the following constraints

$$\sum_{m \in L} \sum_{i \in H \cup L} \sum_{k \in V_m} x_{ij}^{mk} = 1 \quad (\forall j \in H \cup L) \quad (3)$$

$$\sum_{m \in L} \sum_{j \in H \cup L} \sum_{k \in V_m} x_{ij}^{mk} = 1 \quad (\forall i \in H \cup L) \quad (4)$$

❖ Each vehicle departs and returns at the same depot such as satisfies the following constraints

$$\sum_{j \in H} x_{ij}^{mk} = \sum_{j \in H} x_{ji}^{mk} \quad (\forall i = m \in L \text{ and } k \in V_m) \quad (5)$$

❖ Capacity constraints: Vehicle capacity constraints (6) and (7) impose that all the vehicles which leave and return to depot are unloaded.

$$x_{ij}^{mk} = 1 \Rightarrow y_i^k = 0 \quad (\forall i \in L, j \in H \text{ and } k \in V_m) \quad (6)$$

$$x_{ji}^{mk} = 1 \Rightarrow y_i^k = 0 \quad (\forall i \in L, j \in H \text{ and } k \in V_m) \quad (7)$$

For each vehicle of each depot, the load of vehicle k leaving node i to j is:

$$x_{ij}^{mk} = 1 \Rightarrow y_j^k = y_i^k + q_j \quad (\forall i, j \in H \text{ and } k \in V_m) \quad (8)$$

The equation (9) assures that at any time the load, on the vehicle k , must not exceed the vehicle capacity

$$0 < y_i^k \leq Q \quad (\forall i \in H \text{ and } k \in V_m) \quad (9)$$

❖ Time constraints:

For each node i , we introduce a time window $[ET_i, LT_i]$ denoting the time interval in which service at location i must take place. This time windows define:

The arrival time A_j at a destination node j

$$x_{ij}^{mk} = 1 \Rightarrow A_j = D_i + t_{ij}^k \quad (\forall k \in V_m) \quad (10)$$

The service of each customer must start within the applicable time window. If the vehicle arrives before this earliest time, it must wait. The waiting time is

$$ET_i > A_i \Rightarrow W_i = ET_i - A_i \quad (\forall i \in H) \quad (11)$$

The departure time D_i from the node i is:

$$D_i = A_i + S_i \quad (\forall i \in H) \quad (12)$$

The vehicle routes are formed such that:

- The departure and service times at every depot are defined as

$$D_i = S_i = 0 \quad (\forall i \in L) \quad (13)$$

- If departure time from node i is later than the latest time of time window we calculate a tardiness time (14) as follow:

$$T_i = \max(0, D_i - LT_i) \quad (\forall i \in H) \quad (14)$$

- ❖ The precedence constraints:

The pick-up node (f_i) of every couple i must be visited before the corresponding delivery node (c_i) as:

$$D_{f_i} < D_{c_i} \quad (\forall i \in H_c, f_i \in H^+ \text{ and } c_i \in H^-) \quad (15)$$

4 Multi-Objective Optimization

4.1 Multi-Objective Optimization Problem

The Multi-Objective optimization Problem (MOP) has been acknowledged as an advanced design technique in optimization. The reason is that most real world problems are multi-disciplinary and complex; since it is common to have more than one important objective in each problem. In mathematical terms, a multi-objective optimization problem can be formulated as:

$$\min(f^T)$$

where f is the vector-valued objective function defined as:

$$f : D \rightarrow C$$

$$f = (f_1(x), f_2(x), \dots, f_k(x))^T$$

$$x \in D \text{ and } k \geq 2$$

where k is being the number of objectives, D is the feasible set of decision (solutions) vectors size n defined by some constraint functions and C is an area of criteria (objectives) size k . Many multi-objective evolutionary algorithms use the concept of Pareto dominance to rank solutions and to apply selection strategies based on non-domination ranks [36].

4.2 Pareto Dominance Method

Several recent multi-objective algorithms were inspired by non-dominated Pareto concept. The Pareto optimality concept is used to find solutions representing a possible compromise between the criteria [37]. A feasible solution $x_1 \in D$ dominates another solution $x_2 \in D$ if

$$\begin{cases} \forall i \Rightarrow f_i(x_1) \leq f_i(x_2) \\ \exists j : f_j(x_1) < f_j(x_2) \end{cases}$$

The solution x_1 is called Pareto optimal if there is no solution that dominates it. These solutions are noted non-dominated solutions. A subset of the Pareto optimal set is often called the Pareto front. Figure 1 shows an example where we seek to minimize two different functions. The points 1, 3 and 5 are not dominated. Whereas, point 2 is dominated by point 3, and point 4 is dominated by point 5.

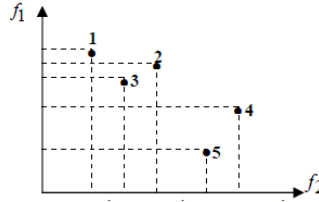


Figure 1
Dominance Example

5 Genetic Algorithm for Multi-Criteria m-MDPDPTW Optimization Problem

5.1 Chromosome Representation

The solutions (individuals) of the m-MDPDP problem are encoded by chromosome path representation. In our given chromosome, every individual includes a number of depots and a gene indicates the node number assigned to a pick-up and delivery point. The sequence of genes dictates the order in which these nodes are visited. The depot number indicates the beginning and the ending of each path. The index "0" is not used throughout all the work. In our multi-criteria genetic algorithms, we simulate the process of evolution for several types of populations in different sizes. Figure 2 represents the solutions under form of chromosome path representation considering two depots ($m=2$) and 16 nodes ($n=16$) numbered 1 to 16 that are 8 couples. The depot number index 17 and 18 indicate the beginning and the end of each path.

Depot1	17	13	4	8	1	10	5	12	15	17
Depot2	18	7	9	3	6	11	2	14	16	18

Figure 2
Solution coding

5.2 Initial Population Structure

5.2.1 Population $P_{\text{couple/depot}}$: Grouping Phase

In our m-MDPDPTW problem multi-depots are considered and each load has to be transported by one of the vehicles, between paired pick-up and delivery nodes. In the grouping phase, we have to determine depots through which nodes are served. And, to be sure that each pair (pick-up node f_i and its associated delivery node c_i) belongs to the same depot, we chose to assign nodes per couple to the nearest depot. The process of grouping is done according to the following role: We calculate for every depot m the distance between each couple C_i and depot d_j according to the mathematical formulation detailed in [38].

Knowing the number of vehicles and requests in each depot this critical couple will be assigned to the depot which has no nodes assigned. If all depots contain couples, we assign to the depot which has more vehicles. If the number of vehicles is the same, we associate these nodes to the depot having the minimum of demands. If all depots have the same number of requests, we select a random depot for assignment. At the end of this simple strategy of grouping, each pair of nodes are assigned to an initial depot and an initial group of potential solution candidates (chromosomes) is randomly generated, constructing the first population size N named $P_{\text{couple/depot}}$. This population represents, for each depot, all couples visited by vehicles associated to these.

Furthermore, this population is used to create a new $P_{\text{couple/depot}}$ containing $2*N$ individuals. The first part of this population represents one copy of the N individuals of population $P_{\text{Best-couple}}$, while the remaining 50 percentage of this population are created by applying GA operators on population $P_{\text{Best-couple}}$.

It is difficult to determine the most effective crossover method in advance. It is advised to use two-point crossover in the case of a large population, the uniform crossover in the case of a smaller population, less cut points in the case of short chromosomes, and more cut points in the case of large chromosomes [39].

In our case, we select two parent chromosomes from population of step 2 by using tournament selection. For recombination, we apply uniform crossover with rate equal to 0.8 and for diversification, we apply swap mutation with a rate equal to 0.2. Figure 3 shows an individual example of the population $P_{\text{couple/depot}}$ indicating the couple of nodes which will be served by each depot. We consider then three depots ($m=3$) and 36 nodes ($n=36$) designed 1 to 36 that are 18 couples. The depot number indexes 37 to 39 indicate the beginning and the end of each path.

Depot1	37	C ₄	C ₅	C ₁₀	C ₁₁	C ₁₈	C ₂	C ₆	37
Depot2	38	C ₃	C ₇	C ₁₄	C ₁₂	C ₁₅	C ₉	38	
Depot3	39	C ₁₇	C ₈	C ₁₃	C ₁₆	C ₁	39		

Figure 3

Individual example of $P_{\text{couple/depot}}$

After applying the regrouping step we have:

7 couples are assigned to depot 1 indexed 37

{ C₂ (3,4), C₄ (5,6), C₅ (18,8), C₆ (1,12), C₁₀ (15,16), C₁₁ (25,36), C₁₈(28,30) };

6 couples are assigned to depot 2 indexed 38

{ C₃ (13,23), C₇ (11,19), C₉ (31,14) C₁₂(20,35), C₁₄(27,10), C₁₅(17,24)}

5 couples are assigned to depot 2 indexed 39

{ C₁ (7, 34), C₈ (26,33), C₁₃ (2,22) C₁₆ (21,9), C₁₇ (29,32)}

5.2.2 Population $P_{\text{vehicle/depot}}$

The second population ($P_{\text{vehicle/depot}}$) indicates the number of couples visited by each vehicle available in each depot. The number of vehicles available is known in advance. Considering the same example below with seven vehicles ($K=7$) distributed as follows: $V_1 = 3$, $V_2 = 2$ and $V_3 = 2$, we can distinguish two types of individuals $P_{\text{vehicle/depot}}$.

First type: All vehicles belonging to the depot i are used. Figure 4 shows an individual example of $P_{\text{vehicle/depot}}$ (type 1).

Second type: We can minimize the number of vehicles available in the depot i and not use the totality. Figure 5 shows an individual example of $P_{\text{vehicle/depot}}$ (type 2). In the depot1, we have three vehicles available, the first vehicle k_1 visits 5 couples, the second visits 2 couples and the last one is not used. Contrary, in the third depot, all vehicles available are used to serve all couples assigned to it.

	k₁	k₂	k₃
Depot1	3	2	2
Depot2	1	5	
Depot3	2	2	

Figure 4

An individual example of $P_{\text{vehicle/depot}}$ (type1)

	k₁	k₂	k₃
Depot1	5	2	0
Depot2	6	0	
Depot3	3	1	

Figure 5

An individual example of $P_{\text{vehicle/depot}}$ (type2)

5.2.3 Population $P_{\text{node/vehicle/depot}}$: Routing Phase

This population named $P_{\text{node/vehicle/depot}}$ represents, for each depot, the order in which all nodes are visited. To construct this population type we should follow two steps: Firstly, using $P_{\text{couple/depot}}$ and $P_{\text{vehicle/depot}}$ size N , we create

$P_{\text{couple/vehicle/depot}}$. This population verifies that couples are assigned to one depot belongs exactly to a single route. After, the indices of couple are replaced by those of the correspondant nodes. Then, these nodes are randomly mixed to generate all individuals of this new population named $P_{\text{node/vehicle/depot}}$. An individual of this population, created after this routing phase, is shown in Figure 6. Considering individual examples of the populations $P_{\text{couple/depot}}$ decoded with $P_{\text{vehicle/depot}}$ given by Figure 3 and Figure 5.

37	8	12	5	15	18	36	25	1	6	16	37	3	30	4	28	37
38	24	17	35	14	10	31	11	19	20	23	27	13	38			
39	32	22	2	34	29	7	39	9	21	33	26	39				

Figure 6

Individuals of $P_{\text{node/vehicle/depot}}$ after Routing phase

5.3 Heuristics for Corrections Procedures

5.3.1 Heuristic Algorithm for Precedence Correction Procedure

This procedure ensures that each delivery node on the same route and the same depot is not visited before its supplier. We must seek gene by gene in each individual if there is a delivery customer for which the supplier has not visited before him. We are looking at the suppliers in the following chromosome and we insert in the position before his delivery points.

Precedence correction procedure applied to individual examples in Figure 6 gives the chromosomes presented in Figure 7. In the first depot, suppliers indexed 6, 16 and 4 are visited after their customers. Their positions went before the nodes 5, 15 and 3. In depot 2 node 19 went before 11 and for the third depot there is no correction.

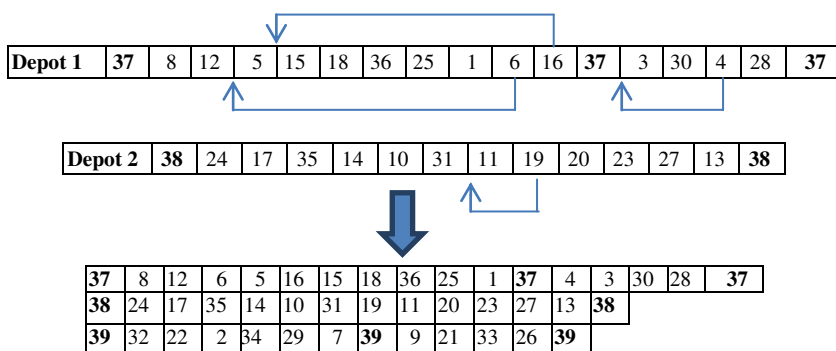


Figure 7

Precedence correction procedure

5.3.2 Heuristic for Capacity Correction Procedure

The capacity correction procedure ensures that the total load of the vehicle must be smaller than or equal to the maximum capacity of the vehicle. We take each individual of the population $P_{\text{node/vehicle/depot}}$ after precedence correction and calculate, at each node, the quantity transported by the vehicle in each route. If it is greater than the maximum of the vehicle, we seek for a supplier whose delivery node has not been served among the following nodes, and we insert it in the position which immediately follows. In Figure 8, capacity correction is applied to individual examples in Figure 6 after precedence correction procedure of Figure 7 with $Q = 80$ and $q_i = 40$ for all nodes i .

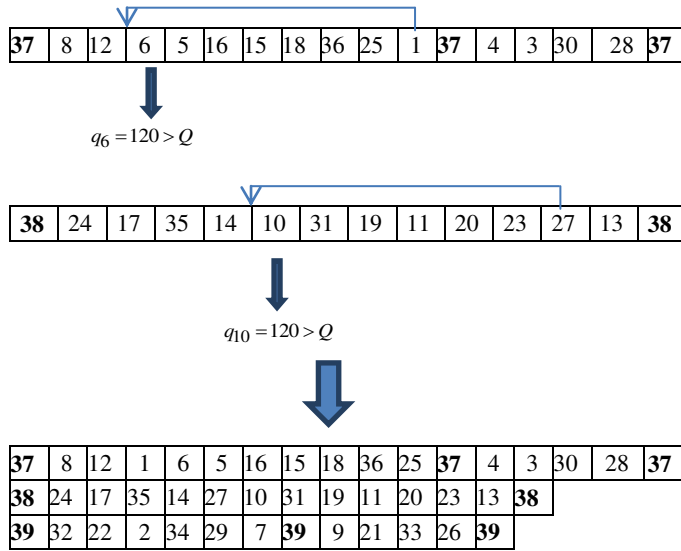


Figure 8
Capacity correction procedure

5.4 Genetic Algorithm for m-MDPDPTW

The developed algorithm for multi-objective m-MDPDPTW problem optimizes the function $f = (f_1, f_2, f_3)$ given by the equation (1) respecting all constraints. Three objectives dimensions are defined as follows:

f_1 = Total travel distance,

f_2 = Total tardiness time,

f_3 = The number of Vehicles required.

These fitness values are determinate for every individual of $P_{\text{node/vehicle/depot}}$ in order to obtain the Pareto population noted P_{Pareto} . The challenge is to find compromise between a values of f_1, f_2, f_3 in order to solve the optimization problem. The Pareto dominance selection strategy is used in our MOP application to differentiate individuals that are clearly superior to others. This one affects ranks for every individual of $P_{\text{node/vehicle/depot}}$. These ranks stratify the population into preference categories. Lower ranks are preferable, and the individuals within rank 1 are the best in the current population. The individuals in each rank set represent a solution which is in some sense incomparable with one another. It considers that an individual I_1 of P_{Pareto} dominates another individual I_2 of a same population if:

$$f_1(I_1) \leq f_1(I_2) \text{ and } f_2(I_2) \leq f_2(I_1) \text{ and } f_3(I_1) \leq f_3(I_2)$$

In addition, two individuals (I_1, I_2) are non-dominated by one over the other if they check a condition of following system:

$$\begin{cases} f_1(I_1) > f_1(I_2), f_2(I_1) \leq f_2(I_2), f_3(I_1) \leq f_3(I_2) \\ f_1(I_1) \leq f_1(I_2), f_2(I_1) > f_2(I_2), f_3(I_1) \leq f_3(I_2) \\ f_1(I_1) \leq f_1(I_2), f_2(I_1) \leq f_2(I_2), f_3(I_1) > f_3(I_2) \\ f_1(I_1) > f_1(I_2), f_2(I_1) > f_2(I_2), f_3(I_1) \leq f_3(I_2) \\ f_1(I_1) > f_1(I_2), f_2(I_1) \leq f_2(I_2), f_3(I_1) > f_3(I_2) \\ f_1(I_1) \leq f_1(I_2), f_2(I_1) > f_2(I_2), f_3(I_1) > f_3(I_2) \end{cases}$$

The different steps of the GA for multi-criteria m-MDPDPTW Optimization problems using Pareto fitness evaluation, Pareto ranking selection and elitism are given by:

Step 1: Read problem instance data and set GA parameters.

Step 2: Apply Depot-Grouping phase developed in section 5.2.1.

Step 3: Generate randomly an initial population $P_{\text{couple/depot}}$ containing N individuals.

Repeat until maximum of generation reached.

Begin

Step 4: Copy the N initial individuals of population $P_{\text{couple/depot}}$ in a new population $P_{\text{Best-couple}}$.

Step 5: Create a new $P_{\text{couple/depot}}$ containing $2*N$ individuals. The first part of this population represents one copy of the N individual $P_{\text{Best-couple}}$, while the remaining 50 percentage of this population are created by applying GA operators on population $P_{\text{Best-couple}}$. We select two parent chromosomes from population of step 2 by using tournament selection. For recombination, we apply one point crossover with rate equal to 0.8 and for diversification, we apply swap mutation with a rate equal to 0.2.

Step 6: Generate vehicle population (section 5.2.2) containing $2*N$ individuals and respecting constraint vehicle numbers.

Step 7: Let us apply routing phase to create $P_{\text{node/vehicle/depot}}$ (section 5.2.3). This population with size $[2*N*m]$ specifies, for each depot, the number of routes (that are vehicles) and the order of delivery and pick-up within each route.

Step 8: Let us apply the precedence then the capacity correction procedure, given in section 5.3, to transform each individual into feasible solution.

Step 9: Let us calculate for every individual of $P_{\text{node/vehicle/depot}}$ fitness values (f_1, f_2 and f_3) in order to obtain the Pareto population P_{Pareto} .

Step 10: Assign one Pareto rank to every individual of $P_{\text{node/vehicle/depot}}$ according to this algorithm:

Algorithm of Pareto rank affection

```

1. R =1
2. Pop size=  $2*N$ 
3. While (Pop size  $\neq$  0)
4. {
5.   For i=1 to Pop size
6.     { if (  $I_i$  is non dominated)
7.       { rank [  $I_i$  ] = R }
8.     }
9.   For i=1 to Pop size
10.    { if (rank [  $I_i$  ] = R )
11.      {remove  $I_i$  from population
12.        Pop size = Pop size – 1
13.      }
14.    }
15. R = R +1
16. }
```

Step 11: Select the N individuals with the lower ranks. Then for each generation, the non-dominated solutions of the population are copied in the old population $P_{\text{Best-couple}}$ at step 4.

End

6 Simulation Results

There are no benchmark test problems available for m-MDPDPTW. Therefore, test problems use the sets instances of Li & Lim's [13] PDPTW benchmark problems namely P01. In these clustered classes there is found only one depot. We

modify it for adapting our problem and add depot node to these instances. The algorithm is coded in C language using Microsoft Visual Studio2010 and run on personal computer Intel Core i7, CPU 2.50 GHz and 6.00 GB memory (RAM) under the operating system Windows 8 Professional. The details of parameters characterizing our problem can be seen in Table 1 and Table 2.

Table 1
Parameters of m-MDPDPTW problem

instances	The number of depots	The number of costumers	The number of vehicles available	The vehicle capacity
LC1	3	102	25	20

Table 2
Indices and coordinate of added depots (m=3)

Id Depots	X	Y
103	40	50
104	0	40
105	88	35

The Euclidean distance between the couples and every depot is computed based on the minimum distance. The instances LC01 are grouped. The number of nodes assigned in each depot after applying the depot-grouping phase (Step 2) is determined in the following table.

Table 3
Number of vehicles and nodes assigned

Instances	Depot index	Number of node assigned	Number of available Vehicle in each depot
LC1	103	38	8
	104	38	8
	105	26	9

After all corrections (precedence and capacity), the couples in each depot are divided into different routes using $P_{\text{vehicle/depot}}$ (type2). It should be noted that our approach provides a set of non-dominated solutions representing a Pareto space from which the maker will make their decision. Best route for the given problem can be seen from Table 4, while considering the population size $N = 20$.

Table 4
Best route for LC1 instances

f_1	f_2	f_3	Best Routes
1924.663	71390.07	11	103 -23-100-5-7-40-38-3-73-60-66-9-4-20-24-11-1-95-92-64-67-6-2-94-102-8-10- 103 -63-70-41-39-61-72-62-99-65-59- 103 -97-96- 103

			104-33-36-13-17-54-57-104-19-15-25-27-104-32-31-34-37-47-45-55-53-16-14-104-35-101-18-12-30-21-49-98-42-44-28-22-43-48-50-46-29-26-104 105-78-68-105-51-56-84-80-93-91-89-90-74-71-69-75-76-77-52-58-105-79-82-83-88-87-85-105-81-86-105
1713.649	72114.192	9	103-60-66-95-92-64-67-5-7-9-4-94-102-6-2-3-73-8-10-20-24-40-38-103-41-39-23-100-11-1-62-99-65-59-63-70-103-97-96-61-72-103 104-19-15-13-17-16-14-32-31-33-36-55-53-47-45-25-27-34-37-54-57-104-30-21-43-46-48-50-18-12-35-101-42-44-29-26-28-22-49-98-104 105-78-68-74-71-105-69-75-105-93-91-89-90-51-56-52-58-76-77-84-80-105-79-82-87-85-81-86-83-88-105
1837.556	107388.461	6	103-6-2-20-24-8-10-95-92-5-7-64-67-60-66-3-73-40-38-9-4-94-102-103-11-1-62-99-65-59-41-39-97-96-23-100-63-70-61-72-103 104-54-57-47-45-30-21-33-36-16-14-25-27-34-37-42-44-13-17-19-15-18-12-55-53-32-31-104-35-48-50-101-49-98-28-22-43-29-26-46-104 105-78-68-69-75-74-76-77-71-105-52-58-93-91-89-90-87-85-51-56-79-82-81-86-83-88-84-80-105
1903.189	77750.510	9	103-60-66-103-6-2-103-94-102-9-4-64-67-8-10-20-24-40-38-3-73-5-7-11-1-95-92-103-23-100-63-62-70-99-103-41-39-65-59-97-96-61-72-103 104-25-27-32-31-33-36-18-12-55-53-19-15-13-17-34-37-16-14-54-57-30-47-45-42-44-21-104-35-101-48-50-28-22-29-26-104-49-98-43-46-104 105-78-68-74-71-51-56-79-82-87-85-89-90-83-88-81-86-52-58-93-91-84-80-69-75-76-77-105
1895.835	79811.345	8	103-64-67-95-92-60-66-6-2-8-10-40-38-9-4-5-7-103-20-24-23-100-63-70-62-99-3-73-11-1-94-102-103-41-39-61-72-65-59-103-97-96-103 104-54-57-19-15-47-45-55-53-16-14-34-37-32-31-33-36-18-12-25-27-42-44-13-17-104-29-26-35-101-30-21-43-46-48-50-49-98-28-22-104 105-89-90-93-91-51-56-52-58-74-71-78-68-76-77-69-75-105-84-80-87-85-83-88-79-82-81-86-105
1889.771	70816.223	11	103-23-100-20-24-8-10-94-102-5-7-11-1-9-4-64-67-3-73-6-2-60-66-40-38-95-92-103-65-59-62-99-41-39-61-72-63-70-103-97-96-103 104-54-57-13-17-25-27-33-36-16-14-19-15-104-32-31-47-45-104-18-12-55-53-34-42-44-30-21-37-104-35-101-28-22-29-26-104-49-98-43-46-48-50-104 105-52-58-93-91-89-90-76-77-74-71-51-56-78-68-69-75-105-87-85-79-82-84-80-105-83-88-81-86-105

The results in Table 4 present the Pareto population P_{pareto} (total travel distance (f_1), total tardiness time (f_2) and the number of vehicles used (f_3)) in the first, second and third columns. In the fourth column we represent the best results found after 50 runs for a population size equal to twenty. The six best solutions represent the set of routes assigned to a fleet of vehicles which satisfies all customer demand without contravening any constraints and minimize total travel distance, total tardiness time and vehicle numbers. For all the depots, the routes pass through all location couples starting from the source location and ends at the same source after serving all customers. It can be observed that the best solution minimizing the total travel distance is the second with a total distance of 1713.649 km using 9 vehicles. For depot 1 located at (40, 50), we have 3 sets of routes generated for 2 different vehicles. In the last solution the number of vehicles used is 11, i.e. three vehicles in the first depot, five in the second and three in the third.

Conclusions

In this paper a m-MDPDPTW was presented as a multi-criteria optimization problem. A state of the art dedicated to evolutionary approaches previously developed was given. Afterward, a mathematical model of the above problem was constructed and an improved chromosome path representation was given to simulate the process of evolution for several types of populations in different sizes. A new Genetic Algorithm approach was proposed as a multiple objectives optimization tool. This algorithm was based on Pareto dominance optimization method using elitism strategy. A major advantage of this algorithm consists of the possibility to find swiftly a set of satisfied solutions when we have a complex case study with many variants and several objectives to minimize. The validity of this new algorithm is proved by simulation and the simulation results show that there is six best solutions representing sets of routes assigned to a fleet of vehicles which satisfies all customer demand without contravening any constraints and minimizes the total travel distance, the total tardiness time and the number of vehicles used. It can be observed that the best solution minimizing the total travel distance is the second with a total distance of 1713.649, the one that minimizes the number of vehicles used is the third with six vehicles and the minimum of total tardiness time is equal to 70816.223 was found in the last solution.

Future work will need to add a clustering algorithm for to choose the optimal locations of depot nodes, we will define an analytic hierarchy process approach (AHP) that aims to refine the decision-making process by examining the coherence and consistency of decision-maker preferences in order to select one route among optimal solutions discovered by applying our new multiple objectives algorithm and we will compare these results using other optimization methods like the Particle Swarm Optimization (PSO) which is a recent heuristic search method similar to the Genetic Algorithm in the sense that they are both population-based search approaches and that they both depend on information sharing among their population members to enhance their search processes using a combination of deterministic and probabilistic rules.

References

- [1] S. N. Parragh, Karl F. Doerner, Richard F. Hartl: A Survey on Pickup and Delivery Problems, Part I, II: Transportation between Customers and Depot", JFB 58: 21-51, Springer-2008
- [2] R. Liu, X. Xie, V. Augusto, C. Rodriguez. Heuristic Algorithms for a Vehicle Routing Problem with Simultaneous Delivery and Pickup and Time Windows in Home Health Care. European Journal of Operational Research. Vol. 230, No. 3, pp. 475-486, 2013
- [3] F. Guerriero, F. Pezzella, O. Pisacane, L. Trollini. Multi-Objective Optimization in Dial-a-Ride Public Transportation. 17th Meeting of the EURO Working Group on Transportation, (EWGT2014), Transportation Research Procedia, Vol. 3, Sevilla, Spain, pp. 299-308, 2014

- [4] J. Lenstra and A. Rinnooy Kan: Complexity of the Vehicle Routing and Scheduling Problems, *Networks international journal*, Vol. 11, pp. 221-228, Springer 1981
- [5] G. Berbeglia, J. F. Cordeau, I. Gribkovskaia and G. Laporte : Static Pickup and Delivery Problems: a Classification Scheme and Survey, Vol. 15, pp. 1-31, 2007
- [6] Bruno Petrato Bruck, Andre Gustavo dos Santos, Jose Elias Claudio Arroyo: Hybrid Metaheuristic for the Single Vehicle Routing Problem with Deliveries and Selective Pickups, *IEEE World Congress on Computational Intelligence WCCI*, June 2012
- [7] J. J. Jaw, A. R. Odoni, H. N. Psaraftis, N. H. M. Wilson: A Heuristic Algorithm for the Multi-Vehicle Advance Request Dial-a-Ride Problem with Time Windows, *Transportation Research Part B: Methodological*, pp. 243-257, 1986
- [8] O. B. G. Madsen, H. F. Ravn, J. M. Rygaard: A Heuristic Algorithm for a Dial-a-Ride Problem with Time Windows, Multiple Capacities, and Multiple Objectives. *Annals of Operations Research*, 60, pp. 193-208, 1995
- [9] M. Diana, M. M. Dessouky: A New Regret Insertion Heuristic for Solving Large-Scale Dial-a-Ride Problems with Time Windows, *Transportation Research Part B: Methodological*, 38, pp. 539-557, 2004
- [10] Q. Lu, M. Dessouky: A New Insertion-based Construction Heuristic for Solving the Pickup and Delivery Problem with Time Windows, *European Journal of Operational Research*, 175, pp. 672-687, 2006
- [11] W. P. Nanry, J. Wesley Barnes: Solving the Pickup and Delivery Problem with Time Windows using Reactive Tabu Search, *Transportation Research Part B: Methodological*, 34, pp. 107-121, 2000
- [12] J.-F. Cordeau, G. Laporte : A Tabu Search Heuristic for the Static Multi-Vehicle Dial-a-Ride Problem, *Transportation Research Part B: Methodological*, 37, pp. 579-594, 2003
- [13] H. Li, A. Lim: A Metaheuristic for the Pickup and Delivery Problem with Time Windows, In *Proceedings of the 13th IEEE International Conference on Tools with Artificial Intelligence*, p. 160, 2001
- [14] G. Pankratz: A Grouping Genetic Algorithm for the Pickup and Delivery Problem with Time Windows, *Or Spectrum*, 27, pp. 21-4, 2005
- [15] S. Ropke, D. Pisinger: An Adaptive Large Neighborhood Search Heuristic for the Pickup and Delivery Problem with Time Windows, *Transportation Science*, 40, pp. 455-472, 2006
- [16] S. N. Parragh, K. F. Doerner, R. F. Hartl: Variable Neighborhood Search for the Dial-a-Ride Problem, *Computers & Operations Research*, 37, pp. 1129-1138, 2010

- [17] R. Liu, X. Xie, V. Augusto and C. Rodriguez: Heuristic Algorithms for a Vehicle Routing Problem with Simultaneous Delivery and Pickup and Time Windows in Home Health Care, *European Journal of Operational Research*, 230(3, pp. 475-486), 2013
- [18] B. Ombuki-Berman, and T. H. Franklin: Using Genetic Algorithms for Multi-Depot Vehicle Routing, *Bio-inspired Algorithms for the Vehicle Routing Problem*, Vol. 161, pp. 77-99, Springer 2009
- [19] H. C. W. Lau, T. M. Chan, W. T. Tsui, and W. K. Pang: Application of Genetic Algorithms to Solve the Multi Depot Vehicle Routing Problem, *IEEE transactions on automation science and engineering*, Vol. 7(2) , 2010
- [20] P. Surekha and S. Sumathi: Solution to Multi-Depot Vehicle Routing Problem Using Genetic Algorithms, *World Applied Programming journal WAP*, Vol. 1(3), pp 118-131, 2011
- [21] C. Prins, P. Lacomme and C. Prodhon :Order-First Split-Second Methods for Vehicle Routing Problems: A review, *Transportation Research Part C* 40, pp. 179-200, 2014
- [22] G. Nagy, and S. Salhi: Heuristic Algorithms for Single and Multiple Depot Vehicle Routing Problems with Pickups and Deliveries, *European Journal of Operational Research*, Vol. 162, pp. 126-141, Elsevier 2005
- [23] X. Wang, C. Xu, and H. Shang: Multi-Depot Vehicle Routing Problem with Time Windows and Multi-Type Vehicle Number Limits and its Genetic Algorithm, 4th IEEE International Conference on Wireless Communications, Networking and Mobile Computing, pp. 1-5, Dalian, China, 2008
- [24] V. Barichard : Approches hybrides pour les problèmes multi objectifs, Doctoral thesis, Angers University, 2003
- [25] I. Harbaoui Dridi, R. Kammarti, P. Borne and M. Ksouri: Multi-Objective Optimization for the m-PDPTW: Aggregation Method With Use of Genetic Algorithm and Lower Bounds, *International Journal of Computers, Communications & Control (IJCCC)*, E-ISSN 1841-9844, Vol. VI, No. 2, pp. 246-257, 2011
- [26] J. D. Schaffer: Multiple Objective Optimization with Vector-evaluated Genetic Algorithms, *The first International Conference on Genetic Algorithms*, pp. 93-100, 1985
- [27] B. Soylu and M. Köksalan: A Favorable Weight-based Evolutionary Algorithm for Multiple Criteria Problems. *IEEE Transactions on Evolutionary Computation*, Vol. 14(2), pp. 191-205, 2010
- [28] I. Harbaoui Dridi, R. Kammarti, P. Borne and M. Ksouri: Genetic Algorithm for Mulicriteria Optimization of a Multi-Pickup and Delivery Problem with Time Windows, 13th IFAC Symposium on Information

- Control Problems in Manufacturing (INCOM'09), Moscow (Russia) pp. 1521-1526, 2009
- [29] A. Zinflou, C. Gagné, and M. Gravel: GISMOO: A New Hybrid Genetic/Immune Strategy for Multiple-Objective Optimization, *Computers & Operations Research*, Vol. 39, No. 9, pp. 1951-1968, 2012
- [30] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan: A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II, *IEEE Transactions on Evolutionary Computation*, Vol. 6, No. 2, pp. 182-197, 2002
- [31] N. Velasco, P. Dejax, C. Guéret, C. Prins : A Non-dominated Sorting Genetic Algorithm for a Bi-Objective Pickup and Delivery Problem, *Engineering Optimization*, 44, pp. 305-325, 2012
- [32] E. Zitzler, M. Laumanns, and L. Thiele: SPEA2: Improving the Strength Pareto Evolutionary Algorithm: Evolutionary Methods for Design Optimization and Control with Applications to Industrial Problem EUROGEN, Athens, Greece, pp. 95-100, 2002
- [33] G. Rudolph, O. Schütze, C. Grimme and H. Trautmann, "A Multi Objective Evolutionary Algorithm Guided by Averaged Hausdorff Distance to Aspiration Sets," In *EVOLVE-A Bridge between Probability, Set Oriented Numerics, and Evolutionary Computation*, pp. 261-273, Springer 2014
- [34] C. A. Coello, Gary B. Lamont and David A. Van Veldhuizen, *Evolutionary Algorithms for Solving Multi-Objective Problems*, 2nd Edition, Springer 2007
- [35] K. Deb, *Multi objective Optimization Using Evolutionary Algorithms*. Chichester, U.K.: Wiley, 2001
- [36] Ş. Aykut, A. Kentli, S. Gülmez, O. Yazıcıoğlu: Robust Multi Objective Optimization of Cutting Parameters in Face Milling. *Acta Polytechnica Hungarica journal*, Vol. 9, No. 4, 2012
- [37] V. Pareto : *Cours d'économie politique*, Genève 1964, Bookstore Droz
- [38] E. Ben Alaia , I. Harbaoui Dridi, H. Bouchriha, P. Borne: Optimization Of the Multi-Depot & Multi-Vehicle Pickup and Delivery Problem with Time Windows using Genetic Algorithm. *International Conference on Control, Decision and Information Technologies (CODIT'13)*, pp. 343-348, 2013
- [39] S. Szénási, Z. Vámosy. Implementation of a Distributed Genetic Algorithm for Parameter Optimization in a Cell Nuclei Detection Project. *Acta Polytechnica Hungarica journal*, Vol. 10, No. 4, 2013

Critical Questions of Knowledge Management Concerning Women on Maternity Leave in Hungary

**Andrea Bencsik, Timea Juhasz, Renata Machova,
Zsuzsanna Toth**

J. Selye University, Bratislavská cesta 3322, SK-94501 Komarno, Slovakia
e-mail: bencsika@ujhs.sk; machovar@selyeuni.sk; tothz@ujhs.sk

Abstract: Hungarian organizations have to solve a lot of problems when their female employees take maternity leave and mothers may stay at home, with their child, for up to three years. During this long period of time, organizations have to organize her substitute, and, more importantly, they also have to insure that her knowledge stays relevant to the organization. Empirical research was conducted last year, concerning the knowledge management processes applied, when a member of the organization goes on maternity leave. Research questions: What can the employer and the employee do in this situation to make the knowledge transfer processes optimal? Also, do both sides feel this knowledge transfer is in their best interest? It is important because preserving knowledge is vital for a company in this special situation. The current article examines these critical questions from the point of view of employers and employees alike. The authors studied whether the career opportunities and the position of employees influence the success of knowledge transfer and whether employers expect special knowledge from their employees. The research was conducted in 2013-2014 in the form of a qualitative and quantitative survey. The results showed that, regarding women on maternity leave, the knowledge transfer conducted, during their maternity leave, was not affected by their position and career prospects at the organization; similarly, the process was not significantly influenced by whether the organizations expected specialized knowledge from their employees or not.

Keywords: knowledge management; maternity leave; motherhood; knowledge transfer; Hungarian practice; labor market

1 Introduction

The member states of the European Union follow different maternity leave practices concerning the entitlement and duration of maternity leave. Hungary is one of those EU member states where both the mother and the father are entitled to stay at home with the child from the beginning – for a longer or shorter period of time. The fact, however, is that the duration of this maternity leave, is one of

the longest in the EU, and many Hungarian families do take advantage of this opportunity.

Their long absence from the labor market is essentially an employment question, both in the case of the employer and the employee who would eventually return to work. The question is whether this long absence will prove to be advantageous or disadvantageous for their later employment. Last year, comprehensive research was conducted to find out what questions and protocols occur at the organizations when one of their female employees goes on maternity leave. How is their knowledge transferred and retained within the organization, and whether or not the two sides feel it is their interest for this knowledge to be retained by the organization while the employee is away?

In order to examine this question, qualitative and quantitative research was conducted among employers and employees alike. The research helped to understand the most timely questions and solutions, which both sides considered important. This article presents some results from the research done among both sides, in order to verify the hypotheses described in the research.

2 Sate of Art

2.1 Some Thoughts Concerning the Hungarian Practice

Before giving a detailed introduction, it may be worth having a brief look at the Hungarian practice regarding these situations.

As it has already been mentioned in the introduction, maternity leave can be very long in Hungary. As a basis, maternity leave may last up to three years from the birth of the child, but if more children are born in the family during this period, the mother may stay away from the labor market for as long as 6-8 years. This is an opportunity which is typically taken by a woman within a family. However, researchers disagree about the ideal length of absence for these women.

Families will get a number of types of financial support that could inspire them to stay at home. Thus, parents taking care of the child will get GYED (child care allowance) until the child reaches the age of 2, or if somebody is not entitled to this, she can get GYES (child care benefit) until the child reaches the age of 3 [30].

However, Bálint-Köllő [4] also calls attention to the fact that the grants which women may apply irrespectively of whether they are active on the labor market or not (like GYES and GYED) strengthen the value of home and may motivate mothers to stay away from work for a longer period of time.

To insure employer interest in hiring employees returning from maternity leave, several employment grants are allotted to them. We can see that this employment policy encourages employers to be open to re-employing these workers.

Research in 2008 [6] found that mothers of young children returning from GYES or GYED face great difficulties reconciling their family (and other external) commitments with the demands of their employers. Also, their long absence from work affected the value of their professional knowledge, which often caused uncertainty and self-esteem problems during their re-integration [26]. Only 54.6% of the 252 women interviewed in the research from 2008 felt their knowledge was up-to-date on their return to work, and only 58% of them trained themselves at home to meet the expectations of the labor market.

According to professional literature, knowledge is valuable whether it is tacit or explicit [33], and every individual and organization should take this into consideration if they want to retain their competitive lead [25]. Leonards [32] defined the basic abilities, that is, knowledge assets, which ensure competitiveness. Human capital appears these days as a category of intellectual capital in professional literature [23]. At the same time a modern HRM today has to conform to the requirements of knowledge-based economies and organizations [15]. An employee with knowledge and skills which are useful to the organization means a valuable asset to the organization, and this knowledge may become the main source of its competitive asset.

For a long time, knowledge management literature has been examining the creation, retention, transfer and utilization of knowledge capital in order to ensure the competitive asset of the organization. The question of how and to whom organizational knowledge may be linked and how this type of knowledge may be transferred has also been in the focus of researchers for a long time [9].

Professional literature [3] considers knowledge transfer as spreading knowledge among individuals and groups within the organization, and this pursuit forms the basis of corporate competitiveness improvement.

From the point of view of knowledge management, the most important elements of organizational culture are trust, communication, and learning. An inappropriate organizational culture may hinder any kind of knowledge building [19], as one of the hardest tasks for a manager is to decide what kind of culture can acquire and process the new knowledge.

According to Davenport and Prusak [18], effective knowledge transfer within an organization is mostly hindered by a lack of trust between the management and the employees. One of the reasons for this mistrust is the power distance between management and their workers: as a result, employees often do not see their leaders as partners at work [5]. This often causes employees to try to retain their knowledge monopoly and consequently, their status [21; 13]. In many cases, this hinders proper knowledge transfer within the organization.

2.2 What We Should Know about Trust

Trust is the base of knowledge sharing in the special situation examined later by the authors. Professional literature examines its role from several aspects in the process of knowledge management, thus it is important to review its relevant features.

Davenport and Prusak [17] claim that knowledge sharing as a requirement is unnatural as people believe that their individual knowledge is important and valuable. This mentality naturally results in hoarding knowledge and a general mistrust towards knowledge coming from other people.

Trust is a capital resource that creates new intellectual capital through the mechanics of combining and sharing knowledge. As a result, trust has a special significance, especially in an innovative environment. Trust is a category of managerial abilities which also defines the relationship between leaders and colleagues. Those employees who trust their superiors are more creative, more willing to take risks and more cooperative [20].

Boon and Holmes [12] claim that trust changes in time, as people become more and more comfortable in the presence of others and as they experience how trustworthy and competent the others are.

Cook and Wall [16] also make a distinction between trust in the management and trust between equal partners. They pointed out that trust at the workplace has a strong effect on several organizational phenomena like contentedness at the workplace, stress, organization commitment, productivity and, which is the most important in this research, knowledge sharing.

Abrams *et al.* [1] claim that trust results in increased and comprehensive knowledge sharing, which makes the process less costly and increases the chance that the knowledge gained from a colleague will be deeper, better understood and overall more useful this way.

We can see from this short review, that the issue of trust, has a key position in the research of several experts and it is no wonder that it has been the center of dependency studies concerning knowledge sharing for many years. Although the target areas and subjects of the research differs, the conclusions overlap as all studies emphasize that knowledge sharing remains an illusion, without trust between the people involved in the process.

Building trust within the organization is not quite the same as building trust between individuals [14]. Alston and Tippet [2] drew this conclusion after studying various research, focusing on organizational culture. They believe that culture and trust both play very distinctive roles in the operation of an organization. Organizational trust can be seen as a multi-level phenomenon which is closely linked to the norms, values and beliefs found in the organizational culture itself.

The basic condition of knowledge transfer is that its participants should speak a “common language,” as forming mutual trust and understanding is indispensable. This does not only mean what we traditionally understand as ‘language,’ but it also includes professional language and a similar degree of professional skill. Personal communication is also vitally important. Physical proximity, similar interests and experience are all factors which contribute to the mutual trust formed between the participants, which in turn persuades them to share their knowledge and experience [10].

Knowledge transfer is only completely successful if it results in some degree of change in attitude, behavior, and it raises new ideas [28].

A well-chosen knowledge sharing tool set has a vital role here as well as its correct application and the conditions of its application [8]. The role of HR is further strengthened by the fact that the correct and unhindered application of knowledge transfer (especially in the case of tacit knowledge) cannot happen without ensuring certain conditions regarding culture forming, ethical behavior, leadership examples etc. handling all these factors is the task of the HR department.

Current research is examining what kind of value the knowledge of employees about to go on maternity leave really represents. Specifically how much of this knowledge can be tied to their personality and in what ways the organizations expect to cope with the loss of knowledge.

The research was conducted between 2013 and 2014, using a Hungarian sample, which means the results and correlations are also typical of the Hungarian practice. The project was called ‘Knowledge Transfer and Retention among Mothers of Young Children.’ The essential point of the sampling was that the opinion of both sides should be seen, so research was done among employees and employers alike. As for the employees, the people who were sampled had all been on maternity leave for a certain amount of time. Regarding the employers, the respondents had either employed people freshly returning from GYES or GYED, or they had an active protocol designed specifically to deal with similar situations. The examination of both sides had two phases. The first was qualitative research with the aim to get to know the problem and the results were used to launch the second, quantitative phase in order to reveal the connections. In-depth interviews were carried out in qualitative research, while in case of the quantitative research, questionnaires were applied in an on-line form. The research results of the two sides will be presented separately to prove the stated hypotheses.

3 Methodology of Research among the Women

3.1 Qualitative Research among the Women

The first part of the research conducted among the women was an exploratory, information gathering examination, with in-depth interviews used as a tool. Using the results of these in-depth interviews, qualitative research was conducted later in order to examine the validity of the hypothesis; the aim was to reveal the connections. The interviews were conducted among 11 respondents. The aim of this article is not to give a detailed account of the results of the interviews: only the most important findings are presented in the following:

- Several organizations realized that they needed to retain the knowledge possessed by their female employees about to go on maternity leave. This realization was more prevalent among the companies where the management had already made steps to develop and retain the knowledge of their employees.
- People taking part in this process found that not all knowledge can be transferred as some of it is added value, depending on the personality of the individual; this knowledge could not be, or could barely be shared.
- The women were aware that their long absence from work affected their professional knowledge, but they did not always do anything to keep their knowledge up-to-date and valuable for their return to work.
- Women returning from maternity leave did not trust the labor-market value of their own knowledge, which caused serious self-esteem problems among several respondents. This had a negative effect on their self-confidence and motivation for re-integration, which in turn affected their successful employment in a negative way.
- The research also showed that not only the open and positive motivation of the mothers is needed in the knowledge transfer process, but it is also necessary to have a supportive organization culture which has already incorporated knowledge management into its everyday practice.

3.2 Quantitative Research among the Women

The interviews done with the mothers made it possible to learn about the questions arising in this particular situation; the reasons and connections will have to be revealed with quantitative research. Based on the qualitative questionnaire, a hypothesis was made, which relied on the experience gained during the in-depth interview; its validity was also supported by quantitative research:

Hypothesis

1) Regarding the women taking part in the research, before they went on maternity leave, the success of their knowledge transfer had been influenced by their career prospects and current position in their organization.

3.2.1 Sampling

The sampling method used was the snowball method, and so the research cannot be considered representative. As it has already been mentioned, the mothers could fill in the questionnaire online. It was seen even during the in-depth interviews that the women were reluctant to speak about certain topics; the knowledge management questions and experiences during their return to work were among these, mostly because of self-esteem problems. Before the actual release, the questionnaire had been tested in cooperation with 4 women; they had no problem interpreting the questionnaire and the questionnaire remained unchanged, as a consequence. The authors applied the snowball-method in collecting the samples by involving organizations, of which the main profile was helping mothers find employment. This method guaranteed the best availability of the people concerned and the highest number of questionnaires. The on-line questionnaire was used on a voluntary basis and was anonymous; the results were processed with SPSS. The final sample number was 263 and there was no sample, which had to be left out of the research because it could not be assessed. The specific data is presented in the following Table 1.

Table 1
Specification of the Sample of Mothers with Young Children

Regional Division of Sample	65.8% Central Hungary, 20.2% Northern-Hungary, 6.1% Western-Transdanubia, 4.6% Northern Great Plain, 3% Southern Great Plain, 0.3% Southern-Transdanubia
Age	19.8% under 20, 58.6% between 31-40, 21.6% over 40
Family Status	70% Married, 16% Stable relationship, 8% Divorced, 5.3% Single, 0.7% Other
Number of Children	46.4% Raising 1 child, 38% Raising 2 children, 13.7% Raising 3 children, 1.9% Raising 4 or more children
Highest level of Qualification	5.3% no secondary degree, 35.7% secondary degree, 57.8% tertiary degree, 1.2% PhD grads

The women could fill in the internet questionnaire anonymously. There were mostly closed questions with only 3 open questions among them. The questionnaire examined 4 life situations, the question groups of which are summarized – partially – in Table 2.

Table 2
System of Questionnaire for Mothers of Young Children

Life Situation 1 (before Having a Child)	What role did the mother have within the organization?
	What career prospects did she have within the organization?
	How was the knowledge management process implemented in the organization?
Life Situation 2 (Pregnancy)	How did the organization manage to replace the mother?
	What tasks did the mother have during the knowledge transfer?
	What were the positive and negative features of the knowledge transfer?
Life Situation 3 (Raising the Child at Home)	What knowledge elements are active and passive at home?
	What is the knowledge management practice towards employees staying at home?
	What are the methods and cooperative opportunities of knowledge refreshment and development with and without the help of the organization?
Life Situation 4 (Returning to Work after Maternity leave)	What chances of return do women have after their maternity leave expires?
	What kind of knowledge management tasks do women and their organizations have in this situation?
	What were the sources of knowledge transfer loss on their return?

4 Interpretation of Research among the Women

Evaluating the results of the questionnaire was done with the help of one- and multiple-variable statistical methods. The one-variable methods were frequency, average and deviation procedures, while the multiple-variable methods included cross-table analysis and ANOVA. The data were evaluated by the SPSS statistical program. The cross-table analysis made it possible to show the similarities and differences between the nominal variables, while in the case of the ANOVA-studies, a one- and multiple-way analysis was done. With the help of the latter, the effect of the nominal variables and their interaction could be examined on the metric variables (5-point Likert scales).

The questionnaire wanted to determine what positions the respondents had occupied before having the baby. 76% of the women asked, claimed they were employees, while 5.3%, 10.3% and 1.9% were low-, mid- and top-level managers. 3.8% had their own business, while 2.7% had not been employed prior to their pregnancy. During the research, three groups were made from the respondents: employees, managers and the people without employment during their pregnancy. Those people who were not employed prior to their pregnancy were left out of the sample, which means the final examination was conducted on 256 women.

Approximately 55.1% of the respondents had career prospects at their organization before going on maternity leave. 63.7% of the respondents had been studying continuously before their pregnancy because of their job. 70.7% of the women taking part in the research were assisted by their employers before their pregnancy to keep their knowledge up-to-date.

The respondents believed that the most effective form of learning before their pregnancy was studying within the organization (40.2%), while about a third of them believed in self-studies and 29.7% saw no difference in the efficiency of studying by themselves or at a organization course.

On announcing the pregnancy, companies had to make sure that a medium or long-term replacement for their employee was available. The reactions of the employers varied wildly. 44.9% of the respondents said their employer was happy about their pregnancy, while 18% claimed their employers were not happy and 29.7% claimed their superiors were indifferent. As it turned out from the answers, 58.2% of the women claimed their employer hired a new colleague to replace them, while 19.1% solved this problem with re-organization, 18.8% divided the extra work among the remaining workers, 2.7% mentioned another method and about 1.2% had to realize that their position was discontinued altogether. It must be pointed out, however, that the Labor Code guarantees that the mother cannot be dismissed from work during their paid leave, that is, legislation limited the options of the employers in this respect.

The research also examined how mothers of young children consider passing their knowledge on before maternity leave advisable. The question was how do career prospects and positions influence women in their decision to take part in the knowledge transfer on their own before leaving. Claims were made which could be graded by the respondents on a 5-point Likert scale. 1 meant 'strongly disagree', while 5 meant 'strongly agree'. The research was done with multiple-way variant analysis, where the statements were the dependent variants, the career prospects and job positions were the independent ones; the subject of the examination also included their separate effects as well as their mutual (interactive) effects on the dependent variable. Table 3 presents some of the statements:

Table 3
Frequency, Average and Standard Deviation of the Answers Regarding Knowledge Transfer

Statement	Agrees	Frequency	Valid Percent	AVG	SD
If a mother of young children goes on GYES and GYED, she should definitely pass her tasks and knowledge to the organization.	Strongly disagree	7	2.7	3.98	1.061
	Rather disagree	14	5.5		
	Equally agree and disagree	62	24.2		
	Rather agree	67	26.2		
	Strongly agree	106	41.4		
	Total	256	100		

Statement	Agrees	Frequency	Valid Percent	AVG	SD
If a mother of young children goes on GYES and GYED, she can pass all her knowledge to her organization.	Strongly disagree	22	8.6	2.96	1.062
	Rather disagree	60	23.4		
	Equally agree and disagree	103	40.2		
	Rather agree	48	18.8		
	Strongly agree	23	9.0		
	Total	256	100.0		
Statement	Agrees	Frequency	Valid Percent	AVG	SD
If a mother of young children goes on GYES or GYED, it is not reasonable to pass all her knowledge to her organization.	Strongly disagree	72	28.1	2.57	1.318
	Rather disagree	57	22.3		
	Equally agree and disagree	63	24.6		
	Rather agree	37	14.5		
	Strongly agree	27	10.5		
	Total	256	100		

The results of the research clearly show that most women feel that knowledge transfer is important in this situation –with about 67.6% of the respondents agreeing – the deviation was one of the smallest in this question. At the same time, the research also revealed that these women could not share every piece of knowledge with their replacement. Concerning the findings of the in-depth interviews it has already been mentioned that organization-specific knowledge is relatively easier to pass on than the knowledge tied to emotional intelligence because the latter is personality-dependent. Typically, the respondents felt that these areas were exactly the ones where knowledge was lost during the transfer. 21.5% of the women who filled in the questionnaire mentioned that there were pieces of information which they could not share with their replacement. They believed the areas where they could share the least amount of knowledge were the following: connection network, task-solving abilities, emotional intelligence, communication skills and professional knowledge. It is clear that emotional intelligence could either not be shared or it can be passed on only with great difficulty.

The question, however, is whether the success of knowledge transfer is influenced by how much the women consider it in their own interest to share their knowledge with their replacement. It can be seen that about a quarter of the women believed that they might not need to share everything, that is, they felt motivated to withhold knowledge. There can be several reasons for this. By sharing all knowledge, they may feel their return to the organization will be endangered, especially because they are no longer protected from being made redundant after their child reaches 3. At the same time, if the mother returns to work before her child is 3, her employment may be discontinued for reasons in relation to the skills of the employee or the operation of the workplace. These reasons include a lack of

positions which suit their skills, qualification or practice of the employee or the employee herself refusing the position offered to her. The employee may also be made redundant if – either deliberately or out of neglect – if she ignores the responsibilities which her work involves or demonstrates behavior which endangers the continuation of her employment. All the above means that if the mothers of young children do not feel their chances of return secure, they are not really motivated to share all their knowledge.

Next, the claims were evaluated through multiple-way variant analysis, where the subject of the examination was how some positions or career prospects affected a given answer. The research verified that the two independent variables were indifferent in the case of all three answers, and, similarly, the interaction of the variables had no effect on the dependent variables.

5 Methodology of Organization Research

5.1 Qualitative Research among the Companies

Besides mothers of young children, organizations were also asked about their opinion concerning the critical questions of the situation presented above. The research was conducted similarly to that of the mothers of young children, with both qualitative and quantitative methods.

Fifty companies were involved in the qualitative research with the help of an interview with a one-on-one managing HR worker. This essay will not present all the data in detail; rather, it will concentrate on the most important findings. The focus of the research was whether the participant companies were prepared with a feasible protocol for the knowledge transfer of mothers of young children temporarily going on maternity leave in order to save the knowledge capital of the pregnant employee for the organization. According to the in-depth interviews, the following statements can be made:

- Most of the examined companies realized that in this situation, that is, when a pregnant woman leaves the organization – even temporarily – conscious effort has to be made to retain her knowledge for the organization.
- There was a developed practice at most of the companies enabling them to retain the knowledge of the mothers of young children and they also encouraged the active participation of the mothers to save the greatest amount of knowledge.
- Many organizations knew that they had to face a loss of knowledge, even with the above method, but they believe that the degree of loss depends on the organizational culture, the maturity of the knowledge management practice, the replacement solution, and the mother of young children herself.

- While mothers of young children were staying at home, most organizations had not developed protocol to assist the mothers to retain their knowledge at home.
- There was no unified practice concerning knowledge refreshment and updating mothers newly returning from maternity leave. The type of actual practice was determined by the organization activities, organization culture and the attitude of the management. Several of the examined organizations had no such practice, but the majority tried to assist young mothers to bring their knowledge up to date, usually in the form of consultation with the colleagues.

5.2 Quantitative Research among the Companies

Based on the findings of the in-depth interviews, quantitative research was launched among the companies. The quantitative research proved the following hypothesis:

Hypothesis

2) Among the companies taking part in the research, the success of the knowledge transfer for mothers on maternity leave is influenced by whether the employer expects special (organization-specific) knowledge from the employees or not.

5.2.1 Sampling

The snowball-method was the chosen sampling technique, and so, the research cannot be considered representative. The aim of the sampling was to collect samples from all Hungarian regions. Unfortunately, there are under-represented regions in the sample – for example, Southern-Transdanubia and the Southern Great Plains – where only a small number of samples were contributed. The final sample number was 80. The features of the sample are presented below (Table 4).

Table 4
Frequency, Average and Standard Deviation of the Answers Regarding Knowledge Transfer

Regional Division of Sample	13.8% Northern Hungary, 3.8% Northern Great Plains, 2.5% Southern Great Plains, 66.3% Central Hungary, 3.8% Central Transdanubia, 8.8% Western- Transdanubia, 1.0% Southern-Transdanubia
Organizational Pursuits	18.8% trade, repair, 18.8% financial pursuits, 12.5% catering, 8.8% building industry, 5% health and social service, 5% transport and storage, 5% estate business, econ. serv., 26.1% other
Size of Organization	28.8% (micro-enterprise with 2-8 people), 28.8% (small enterprise with 9-49 people), 16.3% (medium-sized enterprise with 50-249 people), 26.1% (big enterprise above 250 people)
Enterprise Form of Organization	48.8% Ltd., 20 % Ltd (close corporation), 11.3% individual venture, 6.3% limited partnership, 5% budget organization, 2.5% joint venture, 6.1% other

The questionnaire compiled for the organizations was also available through the Internet to any organization who wished to fill it in. The questionnaire contained mostly closed questions which were built on a nominal and metric scale. Similarly to the questions aimed at the women, this questionnaire also focused on four areas which are summarized in the following Table 5.

Table 5
Questionnaire System for Organizations

Life Situation 1 (before Having a Child)	General features of the organization (pursuits, regional division, size etc.)
	What kind of expectations are there concerning employees' knowledge and skills?
	Is there any differentiation between employees concerning knowledge and if so, how?
	What kind of knowledge management protocol exists within the organization?
	How is the knowledge management process realized in the organization?
Life Situation 2 (Pregnancy)	How does the organization replace pregnant women?
	What knowledge transfer tools are used in this situation?
	What kind of knowledge can the mother choose not share?
	What are the factors of organizing replacement?
	What is the source of knowledge loss?
Life Situation 3 (Raising the Child at Home)	How does the organization keep in touch with the mother on leave?
	Which skills does the mother have to develop at home?
	Do they help in the knowledge retaining process? How?
	What knowledge can the mother at home get which she can later use at the organization?
Life Situation 4 (Returning to Work after Maternity leave)	Is there a return protocol for the mothers of young children?
	Is there a knowledge assessment on the mother's return to work?
	What advantages and disadvantages do re-entrants have concerning knowledge management?
	What is the knowledge refreshment practice within the organization?

The questionnaire was mostly built on nominal and metric scales and variables.

6 Interpretation of Research among the Companies

The results were assessed with the help of one- and multiple-variable methods; regarding the frequency, average, deviation and multiple-variable examinations, the cross-table analysis was chosen to be used. The assessment was done with an SPSS program.

During the examination, 'special knowledge' mostly meant the kind of specific knowledge which was valuable for the organization. 48.4% of the organizations demanded some form of special knowledge from their employees, so there was no surprise when 76.3% of the organizations also required knowledge development, that is, training. There was no significant correlation verified between the expectation for special knowledge and whether there was any need for intra-organizational training (Pearson Chi-square test: 3.078 df: 1 sign: .079 $p > 0.000$). At the same time, most organizations made no difference between their employees regarding their training.

The companies utilized several methods to solve the replacement of their employees. These methods included hiring a new colleague (39.7%), restructuring (30.6%) and dividing the tasks (25.6%). There was no connection between the methods and the type of specialized knowledge which the organizations expected from their employees.

When a young mother goes on maternity leave, her tasks and knowledge are transferred with the help of a person whose position differed at every organization. Typically, the pregnant employee shared her tasks and the attached knowledge herself (41.6%), or a mentor was given this duty (32.7%). There were a few companies where nobody cared about this problem, thinking that no training was necessary (11.9%). During the research, one of the questions was whether there was any correlation between the necessity of having specialized knowledge within the organization and the person who is in charge of knowledge transfer in this situation. The results showed that there was only significant connection where the companies decided that they did not need this type of knowledge management. This meant that when there was a need for specialized knowledge at the organization, only 5.7% had no person responsible for knowledge transfer in similar situations, as opposed to the organizations where there was no need for specialized knowledge, in which case 22.2% did not have a separate person for the task (Pearson Chi-square test: 4.208 df: 1 sign.: 0.040 $p < 0.05$).

The tool used for knowledge transfer was the help of the mother of young children in 29.5% of the cases; there was a documented process description at several companies (26.4%), while others hired mentors (24.8%). 3.1% of the companies used other methods, while 9.3% made no such steps whatsoever. Only in this last case was a significant connection between the applied method and the expectation for specialized knowledge (Pearson Chi-square: 4.208, df: 1 sign.: 0.040 $p < 0.05$). Most of the companies (38.8%) spent less than 2 weeks replacing their pregnant employee, while one organization out of five was willing to spend more than a month on this task. At the same time, 11.3% of the examined companies did not spend any time on this process at all.

It was interesting to see that only 15% of the companies saw any danger of knowledge loss in this situation. In this respect, there was no difference between the companies who expected specialized knowledge and those who did not.

Finally, approximately 40% of the companies claimed that they had a developed protocol to replace their employees on maternity leave or to successfully transfer their task. At the same time, the research indicated that there was no significant correlation between the existence of such a protocol and what kind of knowledge the organizations expected from their employees.

7 Discussion

This study is presenting the tasks and questions appearing during the intra-organizational knowledge transfer of an employee going on maternity leave; during the research, the points of view of both the employees and the employers were taken into consideration. As we could not find any earlier research dealing with this particular situation (going on and returning from maternity leave), the basis for comparing the results with the research found in the professional literature is not provided by previous research but by this research, that is, the process of knowledge transfer.

The hypothesis made during the research with the mothers of young children could not be accepted because the success of knowledge transfer was not influenced by either the career prospects or the position the mother filled before her pregnancy. On the one hand, this contradicts our own experience and our previous research results; on the other hand, the results of international research does not support it either [11] as those results prove that the lack of willingness to share knowledge can, in most cases, be traced back to fear about the individual's career [24].

Generally, it can be said that most women accepted the importance of knowledge transfer in this life situation, although they also clearly saw that they could not pass all their knowledge during the process. This primarily meant that part of their knowledge which could not be handled by mere documentation or by using informatics. The studies indicate that even if there is knowledge transfer in such a case, it is mostly restricted to the information which they are obliged to share and, consequently, it lacks the elements of tacit knowledge.

At the same time, the findings of this research coincided with previous research [21], that is, the women were not necessarily motivated to share their knowledge. They felt that a certain amount of knowledge monopoly may ensure that their knowledge could represent further value to their organization on their return to work. This is more identical to the results seen in other research presented in the professional literature [27].

Their motivation was especially influenced by the fact that a lot of them were not sure whether they could return to work after a long period of absence. This kind of uncertainty often results in mistrust, which, as it was shown in the professional

literature, may be one of the greatest hindering factors for a successful knowledge transfer.

The most recent Hungarian study [29] done by KPMG in 2013-14 also supports this claim.

A high portion of the women taking part in this research (44.9%), stayed at home for 3 or more years, and this long period of absence clearly deteriorated their chances of any re-integration to their previous workplace. This was also verified by earlier research [26] a long absence, coupled with the questions of reconciling work and family life, can greatly influence employers decision whether to employ these women who typically fail to meet the requirements. The current research also showed, however, that those women with future career prospects or higher positions at their previous organizations returned to the world of work sooner than those people with no such advantages.

The research conducted with the organizations showed that there was no typical connection between the expectation for specialized knowledge and the success of knowledge transfer and protocol when one of their employees goes on maternity leave. This means that the original hypothesis is not valid. The research also verified that most organizations do not possess a developed procedure in similar cases. As this protocol is missing from the corporate knowledge management practice, it does not become part of corporate culture either, which otherwise provides a shield for successful knowledge management. The truth is, most organizations are already considering the necessity of knowledge management strategy building and are already utilizing some of the relevant tools in their work, but only a small percentage of the organizations interviewed by the professional literature claimed that they incorporated this strategy in their long-term goals and their everyday routine [31].

Experts point out that the task of the traditional HRM must be extended. This means that its role in knowledge economy must be revised inside and outside the organization as well [15]. Several organizations interviewed in our research were only in a very initial phase in this respect.

The fact that many companies have no such protocol concerning knowledge sharing can be explained as organizations do not really feel the dangers of knowledge loss due to neglectful knowledge transfer, although they are aware that not all knowledge can be transferred even when the effort is made. This result correlates with the results gained from the questionnaires handed out to various co-workers, all of which claim that tacit knowledge can either not be transferred at all or can only be transferred partially. The companies feel the losses, but they have not yet reached the point where they also feel the economic repercussions of those losses [22].

The knowledge transfer process was also influenced – as shown in the in-depth interviews made by companies – by the degree of complexity the mother of young

children had to face at work before her pregnancy. In this process, mothers of young children basically acted as mentors, following their replacement's training and passing their knowledge. In the organizations, pregnant women worked for a period of time agreed with the organization. In this case, there were two basic practices: the pregnant mother could continue to work alone and her replacement only arrived after she had left or the mother could stay at work and do her tasks together with her replacement during the training period. Where the mother was not involved in the training, the organization typically hired a mentor or nobody bothered with the issue: this way, the degree of knowledge loss was not – and could not be – assessed properly. The utilization of the mentoring system has a long history, although its application is often superficial and serves only to share explicit knowledge; the connections rarely run deep enough to allow for long-term cooperation and tacit knowledge sharing as well [8].

It is a highly debated topic in the professional literature concerning how much knowledge can be tied to individuals and to what degree this information be passed on to an organization. The current research can be considered unique because it was conducted in an environment which suited the typical conditions in Hungary; however, it is clearly visible that several knowledge element types – with emotional intelligence among them – cannot or can only be partially shared. Our research conducted last year was aimed at the connections between emotional intelligence and knowledge sharing, and the results clearly showed that organizations which pay attention to emotional intelligence are also able to function better regarding knowledge sharing [7].

In this situation the success of knowledge management processes should be based on communication and trust, which presupposes the cooperation between women going on maternity leave and the organizations. Thus, if the organizations know what can be lost if a colleague leaves the organization, not only temporarily, or the employee feels and understands that her knowledge can stay current within the organization, then the loss, that can be generated in such a situation, could be reduced on both sides.

Conclusion

Knowledge sharing is a basic requirement in an organization's life. This is also true of the special case examined in our research. However, the surroundings, the supervision, the quality and the final usefulness of the above mentioned knowledge sharing, are not well thought out. The factors which play an important role, here are connected to soft skills, human relations, trust, managerial behavior and the organizational structure. It is the HR area which can be most helpful in these areas. Women who leave organizations for a certain period of time should be prepared for their leave, and the organization should keep in touch with them even during their stay at home. Also, steps should be taken to ensure that these women can keep their knowledge up to date to be able to return to work after their leave. The conditions of knowledge transfer and the time allowed for it should be

calculated in every case to meet the requirements of the organization and, in particular, the position. While it is true that most of the respondents are aware of the ever increasing role of such knowledge transfer-stimulating methods and tools like informatics, HR tools, coach-type leadership, new structural organizational forms etc., at the same time, there does not seem to be a genuine breakthrough towards forming a real knowledge sharing culture. On the contrary, we tend to make our own knowledge hidden from the public while paradoxically, we expect the opposite behavior from others. Although it is clearly seen that the organizations of the future look at knowledge as a strategic resource, this vision is not translated into a conscious knowledge management strategy. The next line of research is going to aim in the exploration of the background of this basic contradiction: how are the ethical values of the companies implemented, how is internal knowledge sharing solved and finally, how effectively can these systems operate?

As far as the barriers for the present study are concerned (besides the lack of preparation of the involved organizations), we also have to mention that the willingness to answer was generally very low, not all the regions were available in the same degree and mothers on maternity leave did not speak about their situation with pleasure, as their returning to the labor market is difficult, anyway. We hope that we can carry out following research under more favorable conditions.

References

- [1] Abrams, L. C., Cross, E., Lesser, K., Levin, D. Z.: 'Nurturing Interpersonal Trust in Knowledge-Sharing Networks', *Academy of Management Executive* 17, 4, pp. 64-77. 2003
- [2] Alston, F., Tippet, D.: 'Does a Technology-driven Organization's Culture Influence the Trust Employees Have in their Managers?', *Engineering Management Journal* 21, 2, pp. 3-10. 2009
- [3] Argote, L., and Ingram, P.: 'Knowledge Transfer: a Basis for Competitive Advantage in Organisations', *Organizational Behaviour and Human Decision Process* 82, 150-169. 2000
- [4] Bálint, M., Köllő, J.: 'Labor-Market Effects of Child-Care Support' ('A gyermekgondozási támogatások munkaerő-piaci hatásai') *Esély*, 1-21, 2007
- [5] Bakacsi, Gy., Bokor, A., Császár, Cs., Gelei, A., Kovács, K., Takács, S.: 'Stratégiai emberi erőforrás menedzsment', Budapest, Hungary: KJK-KERSZÖV Jogi és Üzleti Kiadó Kft. 2000
- [6] Bencsik, A., Juhász, T.: 'A nők visszailleszkedése a munkaerő-piacra a gyermekvállalás után', in: *Útkeresés az üzleti és a közszférában*, KHEOPS Scientific Conference Proceedings, 287-296. 2009
- [7] Bencsik, A., Stifter, V., Sólyom, A.: 'Examining Tacit Knowledge Transfer at Hungarian Organizations' ('A tacit tudás átadásának vizsgálata magyarországi szervezeteknél', in: *Aktuális gazdasági és társadalmi*

- attitűdök Magyarországon, KHEOPS Scientific Conference Proceedings, 185-195, 2012
- [8] Bencsik, A., Stifter, V.: Mentor System Rights in Knowledge Sharing, Humánpolitikai Szemle, 5, pp. 3-16, 2012
- [9] Bencsik, A.: Change, Project, Knowledge - Symbiosis of Change and Project Management to Build a Knowledge Management System, LAP Lambert Academic Publishing Germany 2012
- [10] Bencsik, A.: Best practice a tudásmenedzsment rendszer kiépítésében, avagy Tudásmenedzsment kézikönyv menedzserek számára. Pearson Publishing Harlow England, 2013
- [11] Berends, H., van der Bij, H., Debackere, K., Weggeman, M.: 'Knowledge Sharing Mechanisms in Industrial Research', R&D Management 36, 1, 85-95, 2006
- [12] Boon, S. D., Holmes, J. G.: 'The Dynamics of Interpersonal Trust: Resolving Uncertainty in the Face of Risk', in: Cooperation and Prosocial Behaviour Hinde, eds. R.A. and Groebel, J., Cambridge, UK. Cambridge University Press, pp. 190-211, 1991
- [13] Bögel, Gy.: 'Tudás, pénz, hatalom' I.-II. CEO, 6, 1/2. 8-15, pp. 27-33, 2005
- [14] Branzei, O., Vertinsky, I., Camp, R. D.: 'Culturecontingent Signs of Trust in Emergent Relationships', Organizational Behaviour and Human Decision Processes 104, 1, pp. 61-82, 2007
- [15] Chivu, J., Popescu D.: 'Human Resources Management in the Knowledge Management', Informatica Economica, 13, pp. 54-60, 2008
- [16] Cook, J., Wall, T.: 'New Work Attitude Measures of Trust, Organizational Commitment and Personal Need Nonfulfillment', Journal of Occupational Psychology 53, pp. 39-52, 1980
- [17] Davenport, T. H., and Prusak, L. (1998) 'Working Knowledge: How Organisations Manage What They Know', Boston, MA: Harvard Business School Press 1998
- [18] Davenport TH., Prusak L.: 'Knowledge management' ('Tudásmenedzsment') Budapest, Hungary, Kossuth Kiadó 2001
- [19] De Long D. W., Fahey, L.: 'Diagnosing Cultural Barriers to Knowledge Management', The Academy of Management Executive, 43, pp. 113-127, 2000
- [20] Dittmar, J., Jennings, K., Stahl-Wert, J.: 'Trust and Engagement', Leadership Excellence 24, 11, p. 8, 2007
- [21] Dobrai, K., Farkas, F., Karoliny, Zs., Poór, J.: Knowledge Transfer in Multinational Companies – Evidence from Hungary, Acta Polytechnica Hungarica, 9, 3, pp. 149-161, 2012

-
- [22] Hafiza, A., Merduwati, D., Adnan, J., Sa'ari, H.: Challenge in Sharing Tacit Knowledge, in: *Academics' Behavior Towards Developing a Web Portal for Sharing Research Ideas*, Proceedings of the European Conference on Information Management, pp. 337-348, 2013
- [23] Heasli, A., Boxall, P.: 'When Knowledge Management Meets HR Strategy: an Exploration of Personalization-Retention and Codification-Recruitment Configurations', *The International Journal of Human Resource Management*, pp. 1955-1975, 2005
- [24] Hsiu-Fen, L.: 'Knowledge Sharing and Organisation Innovation Capability: an Empirical Study', *International Journal of Manpower* 28, 3/4, pp. 315-332, 2007
- [25] Hvorecky, J. Simuth, J., Lichardus, B.: Managing Rational and Not-Fully-Rational Knowledge, *Acta Polytechnica Hungarica*, 10, 2, pp. 121-132, 2013
- [26] Juhasz, T.: 'Családbarát munkahelyek, családbarát szervezetek', unpublished PhD Dissertation, Széchenyi István University, 2010
- [27] 'Knowledge Sharing in the European Research Area': (ERA) Report of the ERA Expert Group, Luxembourg: Office for Official Publications of the European Communities. 2008
- [28] Kő, A., Vas, R., Molnár, B.: 'Az információs társadalom tudástranszfer innovatív módjai', Budapest, Hungary: MTA Információtechnológiai Alapítvány, 2003
- [29] KPMG Academy: 'Organizational Knowledge Sharing in Hungary 2013-2014' ('Szervezeti tudásmegosztás Magyarországon 2013-14') Research report, 2014
- [30] KSH: 'A válság munkaerő-piaci következményei 2010-2011 I. félév', pp. 1-15, 2011
- [31] Lee, Ch. F., Tsai, S. D., Amjadi, M.: 'The Adaptive Approach: Reflections on Knowledge Management Models', *Journal of Management Inquiry* 21, 30, originally published online 1st June 2011
- [32] Leonards, D.: 'Core Capabilities and Core Rigidities A paradox in Managing New Product Development', *Strategic Management Journal* pp. 111-125, 1992
- [33] Polányi, M.: *Personal Knowledge—Towards a Post Critical Philosophy*, London, UK: Routledge and Kegan Paul, 1962

A New Statistical Method for Ranking of Light Sources based on Subjective Points of View

Éva Orbán-Mihálykó¹, László Koltay¹, Ferenc Szabó², Péter Csuti², Renáta Kéri², János Schanda^{2†}

¹ University of Pannonia, Faculty of Information Technology, Department of Mathematics, Egyetem u. 10, H-8200 Veszprém, Hungary, email: orbane@almos.uni-pannon.hu, koltay@almos.uni-pannon.hu

² University of Pannonia, Faculty of Information Technology, Department of Electrical Engineering and Information Systems, Egyetem u. 10, H-8200 Veszprém, Hungary, e-mail: szabo.ferenc@virt.uni-pannon.hu, csuti.peter@virt.uni-pannon.hu, keri.renata@virt.uni-pannon.hu, schanda.janos@virt.uni-pannon.hu

Abstract: A new method of ranking different light stimuli based on subjective points of view is presented. The objects are pairwise compared and ranked on the basis of the judgments of the observers. More than two options for judgment are allowed. Observers' perceptions are considered as random variables. The differences between the sensations are supposed to be independent, identically distributed random variables with Gauss distribution and equal standard deviations. On the basis of the judgments of the observers the expectations of the random variables are estimated by maximum likelihood method and the maximizations are carried out numerically. Computations were performed by the statistical program package R. The rank of the expectations is considered to be the rank of the observers' perception under the test light stimuli. Equalities of the expectations are tested by likelihood ratio tests. The results are compared to the results derived by the AHP method. Finally, some results in connection with the investigated questions are presented.

Keywords: color quality; LED; lights; ranking; pairwise comparison; statistical evaluation; Thurstone method; AHP

1 Introduction

The application area of Light Emitting Diodes (LEDs) in lighting technology has been growing significantly. LEDs are used nowadays not only as signaling lights but also as functional lighting in public lighting, home [1] and shop lighting [2], museum lighting [3], sport lighting and so on. At the beginning of the LED era, phosphor converted white LEDs had been used as a light source for general lighting. Nowadays, phosphor white LEDs are often supplemented by narrow

band color LEDs in order to tailor the light spectrum for different special applications. This results that one given light at a given correlated color temperature can be realized as an unlimited number of composition of phosphor white and color LEDs.

The human visual system has photoreceptors (rods and cones) at the retina, which have different sensitivities for optical radiation. The photopic (daylight) vision is realized by the cones, containing three different opsins that result in three different sensitivities. Figure 1 shows the different cone sensitivities along the visible wavelength domain (380-780 nm).

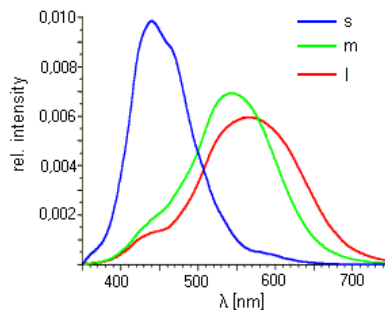


Figure 1

Spectral sensitivity of the human cone photoreceptors (short, medium, long)

In order to evaluate the lighting quality of a light source under development, often, human visual experiments are used [4, 5]. During the previous decade, this kind of visual experiments were carried out by using lighting booths with miniature models of real objects or small objects (e.g. fruits, vegetables) which fit into the viewing booth. In order to investigate the lighting quality with total immersion of the observers, two full-scale laboratory rooms have been developed at the Virtual Environments and Imaging Technologies Research Laboratory at the University of Pannonia. One room simulates a living room, while the other simulates a kitchen environment with a dining area. Each room is equipped with 20 channel LED luminaires, where the spectrum of the illumination could be varied on demand.



Figure 2

Part of the living room and the kitchen environment

Figure 2 shows part of the kitchen environment (right) and the view of the living room (left).

Each LED luminaire contained 20 different types of LEDs: 17 channels of colored LEDs and three channels of white LEDs (phosphor converting ones) each with different correlated color temperature. Figure 3 shows the spectra of the different LEDs used. The channel with the shortest peak wavelength has its maximum emission at 414 nm (deep blue), the maximum emission wavelength of the deepest red LED is 691 nm. One channel has serial connected LEDs with the same color which can be set individually via computer control. The control method of the different LED channels is based on the DMX light control technique. One can set the current of each channel in 256 steps up to the present maximal drive current.

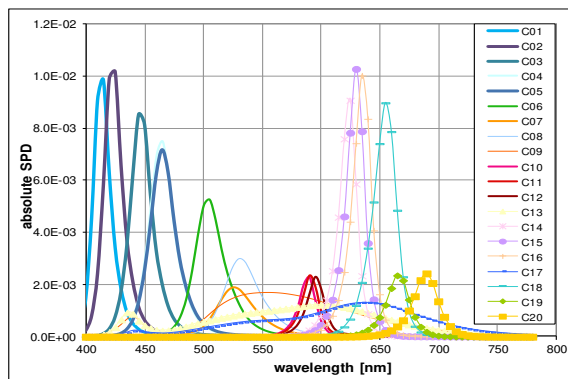


Figure 3

Spectra of different LEDs incorporated in the LED luminaires

By using LEDs with different colors, the spectral power distribution (SPD) of the light can be tailored to fit the requirements of lighting in a particular situation, or to help the human visual system in the actual situation. As the methodology of the human visual system and the process of human vision is very well described and standardized by publications of the International Commission on Illumination (CIE), general trends can be drawn. LED based light sources with different spectral power distribution cause significantly different visual appearance of object colors, even if the color (or correlated color temperature) of the output light is the same.

To perform and evaluate human visual experiments we take into consideration that the sensation of light is based on the observer's perception, therefore, it is always subjective. It depends on the personality of the observer, on the circumstances, moreover, the actual mood and state of mind of the observer and so on. The factors of the sensation can be detailed and examined but presumably all of them cannot be taken, totally into consideration [6, 7]. On the whole, the sensation of light can be regarded as an uncertain phenomenon. Moreover, it is very difficult to measure the sensations. Many questions arise: what is the border-line between equal and different senses, what is the unit, is it the same for all people? Are the differences multiplicative or additive? Is it reasonable to ask the observers to rank the sensations or rather decide between two sensations?

What can be expected from people, based on their perception, is to answer the question which light is preferred over another light. This can be done several times and independently of the opinions of other people. Then, by summarizing the results of the decisions on pairs, by many people, one may determine the rank of the objects. This approach requires a statistical evaluation method based on pairwise comparisons.

2 A Short Review of the Pairwise Comparison Methods

In statistics, two frequently applied methods can be found for ranking based on pairwise comparisons. One of them is AHP (Analytic Hierarchy Process by Saaty [8]). This method is really widespread and generally accepted in management and its possibility in decision making shows great variety [9].

In the AHP method the objects are pairwise compared, and the results of these comparisons are characterized by positive numbers. The larger the number is, the larger the difference is between the objects. The reverse pair is characterized by the reciprocal. The values are included in a matrix, the maximal eigenvalue of which is positive, its multiplicity equals 1 and the normalized eigenvector belonging to that eigenvalue has only positive coordinates [10]. The rank of the coordinates of the normalized eigenvector is considered to be the rank of the objects compared. The opinion of more than one person can be aggregated in a single matrix taking the geometric mean of the values belonging to the separate opinions. The main advantage of the method is that it can be executed easily, the rank can be determined unambiguously. Unfortunately, it does not provide information about palpability, that is about the measure of the difference in senses which is imperceptible and it is difficult to provide a test whether the weights of the objects can be considered equal or they are significantly different.

Another frequently applied pairwise comparison method is the Thurstone method [11]. Thurstone assumed that the differences of the senses are proportional to certain quantities. His idea can be interpreted as follows: the senses are random variables, therefore so are their differences. Expectation of the differences is the difference of the expectations; the dispersion of the differences can be expressed by the covariance matrix of the random variables characterizing the sense of the objects. Assumptions concerning the covariance matrix characterize the Thurstone method (I, II, ..., V). The most frequently used method is Thurstone V [12], which assumes normal (Gauss) distribution with independent latent random variables with equal dispersions. It provides a closed form for the estimations of the expectations. Its advantage is that the formula can be easily computed, but Thurstone V is very sensitive to those values which are used for $\Phi^{-1}(0)$ instead of $-\infty$ and $\Phi^{-1}(1)$ instead of ∞ , where Φ is the standard normal cumulative distribution

function. Another disadvantage is that it permits only two options in the choice, namely worse and better. It is reasonable to allow more than two options, for example, “equal” if there is no too much difference in senses or perhaps “much worse” or “much better”, as well.

In this paper a Thurstone-motivated model for ranking lights is introduced. We keep the assumption of normally (Gauss) distributed latent random variables assigned to the sense of lights. More precisely, we suppose that the differences of the senses are charged with random errors and these errors are considered independent. The maximum likelihood method was applied to estimate the expectations of the latent random variables. Results were checked by performing the AHP method as well. A possible link between the AHP weights and the expectations is presented. To test the equality of the expectations the likelihood ratio test was applied. The steps of the evaluation process are shown through a detailed example. The results of a survey for different LEDs tested for shop lighting is also presented.

3 The Model

Let the number of objects (for example light sources, LEDs) investigated be denoted by n . Let the objects be characterized by the latent multidimensional random variable $\underline{\xi} = (\xi_1, \xi_2, \dots, \xi_n)$ with expectation $E(\underline{\xi}) = \underline{m} = (m_1, m_2, \dots, m_n)$. The random variable ξ_i , $i=1, 2, \dots, n$ features the sensation generated by the i^{th} light in the observers. The observers judge about $\eta_{i,j} = \xi_i - \xi_j$, $i < j$, $i=1, 2, \dots, n-1$, $j=2, \dots, n$. Now $E(\eta_{i,j}) = m_i - m_j$. Let us assume that $\eta_{i,j}$ are independent identically distributed random variables with equal dispersions and suppose them to be Gaussian. Without any restriction, the dispersion can be fixed at 1. Applying the usual notation $N(m, \sigma^2)$ for Gaussian, $\eta_{i,j} \sim N(m_i - m_j, 1)$. These assumptions were used earlier for economic problems in the case of two options to choose in [13].

In our model the number of options is increased. Five choices are allowed for the observers. First, the two compared objects can be equally preferable if the observer is not able to decide for any of them. Moreover, one of the objects can be more preferable than the other, or it can be less preferable than the other, it can be much more preferable than the other and much less preferable than the other.

The judgment is in connection with the value of the latent random variables as follows. If there is no essential difference between the senses, the observer states that the objects are equally preferable. This happens in the case, when the latent random variable $\eta_{i,j}$ satisfies the inequality $|\eta_{i,j}| < d$, with a positive parameter d . The observer states that the i^{th} object is more preferable than the j^{th} object, if $d \leq \eta_{i,j} < Kd$ with a fixed parameter value $1 < K$. The observer states that the i^{th} object is much more preferable than the j^{th} object if $Kd \leq \eta_{i,j}$. On the other hand, the observer states that the i^{th} object is less preferable than the j^{th} object if the

inequality $-Kd \leq \eta_{i,j} \leq d$ holds. Finally, the observer states that the i^{th} object is much less preferable than the j^{th} object if $\eta_{i,j} < -Kd$ is satisfied. The listed inequalities express that the random variable $\eta_{i,j}$ takes its values from special intervals as follows (Figure 4).

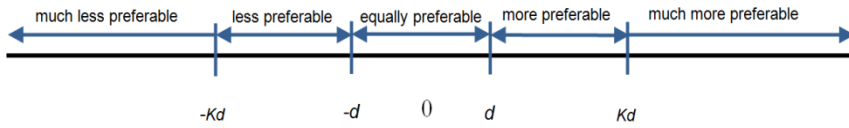


Figure 4

Judgments in the function of the value of the difference of latent random variables

The probabilities of these events can be given by the cumulative distribution function Φ depending on the parameters \underline{m} , d and K and these can be seen in Table 1. Due to the continuousness of the random variables the equalities do not change the values of the probabilities.

Table 1
Options of judgments and their probabilities

Opinion: i^{th} object is ...the j^{th} object	Code f	Probability $P_{i,j,f}$
much less preferable than	1	$P(\eta_{i,j} < -Kd) = \Phi(-Kd - (m_i - m_j))$
less preferable than	2	$P(-Kd \leq \eta_{i,j} \leq -d) = \Phi(-d - (m_i - m_j)) - \Phi(-Kd - (m_i - m_j))$
equally preferable to	3	$P(\eta_{i,j} < d) = \Phi(d - (m_i - m_j)) - \Phi(-d - (m_i - m_j))$
more preferable than	4	$P(d \leq \eta_{i,j} < Kd) = \Phi(Kd - (m_i - m_j)) - \Phi(d - (m_i - m_j))$
much more preferable than	5	$P(Kd \leq \eta_{i,j}) = 1 - \Phi(Kd - (m_i - m_j))$

The opinions of the observers are included in the indicator variables $X = (X_{i,j,f,k})$, $i=1,2,\dots,n-1$, $j=2,\dots,n$, $i < j$, $f=1,2,3,4,5$, $k=1,2,\dots,r$ where r is the number of observers. In detail, the values of the sample based on the opinion of the k^{th} observer comparing the i^{th} and j^{th} objects are summarized in Table 2.

Table 2

Values of the sample in case of the possible opinions of the k^{th} observer comparing the i^{th} and j^{th} objects

Opinion	$X_{i,j,1,k}$	$X_{i,j,2,k}$	$X_{i,j,3,k}$	$X_{i,j,4,k}$	$X_{i,j,5,k}$
much less preferable	1	0	0	0	0
less preferable	0	1	0	0	0
equally preferable	0	0	1	0	0
more preferable	0	0	0	1	0
much more preferable	0	0	0	0	1

Obviously, for any fixed value of i, j, k $\sum_{f=1}^5 X_{i,j,f,k} = 1$. For further computations

let us define the aggregate samples $A_{i,j,1} = \sum_{k=1}^r X_{i,j,1,k}$ as the number of observers who state that the i^{th} object is much less preferable than the j^{th} object;

$A_{i,j,2} = \sum_{k=1}^r X_{i,j,2,k}$ as the number of observers who state that the i^{th} object is less

preferable than the j^{th} object; $A_{i,j,3} = \sum_{k=1}^r X_{i,j,3,k}$ as the number of observers who

state that the i^{th} object is equally preferable to the j^{th} object; $A_{i,j,4} = \sum_{k=1}^r X_{i,j,4,k}$ as

the number of observers who state that the i^{th} object is more preferable than the j^{th} object; and $A_{i,j,5} = \sum_{k=1}^r X_{i,j,5,k}$ as the number of observers who state that the i^{th} object is much more preferable than the j^{th} object.

4 Likelihood Function of the Sample in the Function of the Parameters

The values of the parameters are estimated on the basis of the sample. In statistics, a frequently used method of estimation is the maximum likelihood method [14, 15]. Its main point is to compute the probability of the actual sample as a function of the parameter(s) and to find those values of the parameters where the probability reaches its maximum. The argument, when the probability has its maximal value is called the maximum likelihood estimation of the parameter(s). The probability of the sample is called the likelihood function.

Let the vector of parameters be denoted by $\underline{\vartheta} = (m_1, m_2, \dots, m_n, d, K)$, where $m_i \in R$, $0 < d$ and $1 < K$. Assuming the independence of the opinions of the observers, the likelihood function is

$$L(X, \underline{\vartheta}) = \prod_{i=1}^{n-1} \prod_{j=i+1}^n p_{i,j,1}^{A_{i,j,1}} \cdot p_{i,j,2}^{A_{i,j,2}} \cdot p_{i,j,3}^{A_{i,j,3}} \cdot p_{i,j,4}^{A_{i,j,4}} \cdot p_{i,j,5}^{A_{i,j,5}}, \quad (1)$$

when the values $p_{i,j,f}$ are included in Table 1. $L(X, \underline{\vartheta})$ is positive and it has its maximum at the same point when its logarithm has. Let us denote by $T = R^n \times R^+ \times \{y \in R : 1 < y\}$ the domain of parameter $\underline{\vartheta}$. The maximum likelihood estimation of

the parameter \underline{g} is that $n+2$ dimensional vector in T where the above functions $L(X, \underline{g})$ and $\log L(X, \underline{g})$ have the maximum. That is

$$\hat{\underline{g}} = \arg \max_{\underline{g} \in T} L(X, \underline{g}) = \arg \max_{\underline{g} \in T} \log L(X, \underline{g}) \quad (2)$$

Due to the very complicated form of the likelihood function, an explicit form for the argument cannot be given. Consequently, numerical methods were applied to find the argument of the optimum. Unfortunately the uniqueness of the argument where the likelihood function reaches its maximum is not proved, nevertheless, in practice no problem it was experienced performing numerical optimization.

The rank of the estimated values of expectations $\hat{m}_i = \left(\hat{\underline{g}} \right)_i$ $i=1, 2, \dots, n$ provides the rank of the objects. The estimated value of d equals $\hat{d} = \left(\hat{\underline{g}} \right)_{n+1}$. It serves information about the perceptible border-line. The multiplier which characterizes the category “much” is estimated by $\hat{K} = \left(\hat{\underline{g}} \right)_{n+2}$.

5 Likelihood Ratio Test for the Equality of the Expectations

The advantage of the maximum likelihood estimation is the fact that the testing of hypotheses connected to the estimated values is elaborated. To highlight the meaning of that: if some difference among the estimated values of the parameters m_i $i=1, 2, \dots, n$, can be realized, then the question arises if this difference is significant or not. In other words, the differences are due to the randomness of the sample or they are too large to be explained by the random sample. To decide about this question, the likelihood ratio test can be applied [15].

First, the equality of all the expectations can be tested. In this case the null-hypothesis is $H_0: m_i = m_j$ for all values of i and $j, i \neq j$, the alternative hypothesis looks $H_1: m_i \neq m_j$ for at least one pair of different i and j . One can check that the probabilities in Table 1 depend only on the difference of expectations, hence one can fix $m_1=0$. In this case we can simplify for $H_0: m_i = 0$ for all values of $i=2, 3, \dots, n$, and $H_1: m_i \neq 0$ for some value of $i=2, 3, \dots, n$.

For the sake of simplicity we use notation $T_0 = \{0\}^n \times R^+ \times \{y \in R : 1 < y\}$ and $T_1 = \{0\} \times R^{n-1} \times R^+ \times \{y \in R : 1 < y\}$. The test statistics for testing H_0 is

$$D_t = -2 \log \left(\frac{\sup_{\underline{\theta} \in T_0} L(X, \underline{\theta})}{\sup_{\underline{\theta} \in T_1} L(X, \underline{\theta})} \right). \quad (3)$$

If H_0 is fulfilled, then $D_t \sim \chi_{n-1}^2$ asymptotically, where χ_{n-1}^2 denotes the Pearson chi-square distribution with degree of freedom $n-1$ [15]. Consequently, if the value of the test statistics is above the critical value of the chi-square distribution belonging to the significance level α , then there is a significant difference among the expectations at the significance level α , consequently H_0 is rejected.

Moreover, we can test if there exists a significant difference between the i^{th} and j^{th} object for fixed values of i and j , $i \neq j$. To formulate the statistical problem, now the null-hypothesis is $H_0: m_i = m_j$ for fixed values of i and j , $i \neq j$, the alternative hypothesis is $H_1: m_i \neq m_j$ for these fixed values of i and j . First we notice that the hypothesis is symmetric in i and j , so we can assume that $i < j$. Now, fix $m_i = 0$, then $H_0: m_j = 0$ versus $H_1: m_j \neq 0$ for the fixed value of j . Apply the notations for the parameter spaces $T_i = R^{i-1} \times \{0\} \times R^{n-i} \times R^+ \times \{y \in R : 1 < y\}$ and $T_{i,j} = R^{i-1} \times \{0\} \times R^{j-i-1} \times \{0\} \times R^{n-j} \times R^+ \times \{y \in R : 1 < y\}$, $i < j$. The test statistics is

$$D_{i,j} = -2 \log \left(\frac{\sup_{\underline{\theta} \in T_{i,j}} L(X, \underline{\theta})}{\sup_{\underline{\theta} \in T_i} L(X, \underline{\theta})} \right). \quad (4)$$

Now, asymptotically, $D_{i,j} \sim \chi_1^2$. If the value of the test statistics is above the critical value of the chi-square distribution with degree of freedom 1 belonging to the significance level α , then there exists a significant difference between the expectations m_i and m_j at the significance level α .

6 Statistical Evaluation Process

In this section the steps of the maximum likelihood estimation (MLE) and the likelihood ratio test presented in Section 4 are followed on an example. For the next part of this chapter, neither the physical meaning of the objects, nor the question itself is taken into account, we only concentrate on the consequences of the data.

For ranking purposes, 5 LED based lights (having the same correlated color temperature but different spectral content) were compared pairwise by 48 observers. Each of the observers made 10 observations and decided about the questions: which one of the two objects is more preferable. The judgments of the observers in connection with the questions are included in Table 3.

Table 3
Aggregate opinion of the observers

$A_{i,j,f}$	$f=1$	$f=2$	$f=3$	$f=4$	$f=5$
$i=1,j=2$	5	11	21	11	0
$i=1,j=3$	4	21	11	6	6
$i=1,j=4$	3	16	18	8	3
$i=1,j=5$	8	7	7	13	13
$i=2,j=3$	11	14	19	2	2
$i=2,j=4$	3	16	23	6	0
$i=2,j=5$	4	9	13	7	15
$i=3,j=4$	3	13	18	14	0
$i=3,j=5$	4	9	5	16	14
$i=4,j=5$	4	6	20	11	7

Altogether 480 data are contained in this aggregate table. Recall, that the number $A_{1,2,1}$ presents that 5 observers think that the 1th object is much less preferable than the 2nd one. The numbers $A_{1,2,2}$, $A_{1,2,3}$, $A_{1,2,4}$ and $A_{1,2,5}$ present how many observers state that the 1st object is less preferable, equally preferable, more preferable, and much more preferable than the 2nd one, respectively. We can see that there is a large variety in the opinions. Using these sample values, the likelihood function (1) and its logarithm, the log-likelihood function are given in the function of the parameter $\underline{\theta}$. Fix $m_1 = 0$, and we search the point when the log-likelihood function has its maximum. After performing numerical optimization, we obtain the point

$\hat{\underline{\theta}} = (0, -0.007, 0.287, 0.197, -0.245, 0.453, 2.76)$. This means, that the estimated values of the parameters are $\hat{m}_1 = 0$, $\hat{m}_2 = -0.007$, $\hat{m}_3 = 0.287$, $\hat{m}_4 = 0.197$, $\hat{m}_5 = -0.245$, $\hat{d} = 0.453$, $\hat{K} = 2.76$. The rank of expectations and that of the objects (decreasing) is: 3, 4, 1, 2, 5. The average border-line when the observers are able to distinguish objects is characterized by the number 0.453, and the factor between more preferable and much more preferable is about 2.76. This means that if the difference between two sensations is between -0.453 and 0.453, then an average observer cannot distinguish sensations. The sign refers to the priority. If the difference in the values of the two latent random variables is more than $0.453 \cdot 2.76 \approx 1.250$, then the difference in sensations is characterized by category “much” (Figure 5).

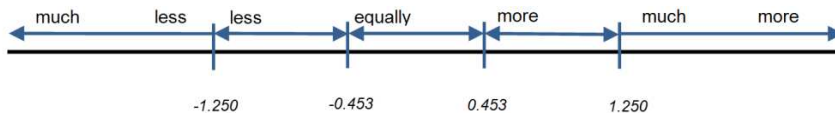


Figure 5
Estimated values of the judgment bounds

The calculations and numerical optimization were performed by the statistical program package R applying the function MLE [16]. In this function the initial values and the multivariate methods for finding the optimum can be changed. In practice we experienced stability concerning the initial values and methods.

To test whether all the expectations can be considered equal or not, the hypothesis is $H_0 : m_1 = m_2 = \dots = m_5$. Performing the likelihood ratio test, the value of the test statistics (3) equals 35.93. It is so large that H_0 is rejected at any level of significance.

On the basis of the estimated expectations one can realize that the expectations of the 1st and 2nd objects are close to each other. The small difference between the estimated expectations may be due to the randomness of the sample. To decide about it, perform the pairwise likelihood ratio test.

First, test the hypotheses $H_0 : m_1 = m_2$ with the alternative hypothesis $H_1 : m_1 \neq m_2$. The value of the test function (4) equals $D_{1,2} = 0.005$. The critical values belonging to the chi-square distribution with degree of freedom 1 are denoted by $\chi^2_{1,\alpha}$. At $\alpha = 0.1$, $\alpha = 0.05$, $\alpha = 0.01$ these values are $\chi^2_{1,0.1} = 2.74$, $\chi^2_{1,0.05} = 3.84$, and $\chi^2_{1,0.01} = 6.63$, respectively. The value of the test function (4) equals 0.005. It is less than all of the above critical values, consequently the equality of the 1st and 2nd objects is accepted at any level of significance.

Generally, test the hypotheses $H_0 : m_i = m_j$ versus $H_1 : m_i \neq m_j$ for fixed values of i and j , $i \neq j$. Making these pairwise tests the values $D_{i,j}$ of the test functions by (4) and the levels of significance at which the equality of expectations is accepted are included in Table 4. Deciding on the usual significance level $\alpha = 0.05$, the results of the test $H_0 : m_i \neq m_j$ versus $H_1 : m_i \neq m_j$ can be seen in Table 5.

Table 4
The values of the test statistics $D_{i,j}$ given by (4) and significance levels to the test values

	$j=1$		$j=2$		$j=3$		$j=4$		$j=5$	
i	$D_{i,j}$	α	$D_{i,j}$	α	$D_{i,j}$	α	$D_{i,j}$	α	$D_{i,j}$	α
1	-	-	0.005	0.943	8.987	0.003	4.296	0.038	6.495	0.013
2	0.005	0.943	-	-	9.320	0.002	4.534	0.033	6.083	0.014
3	8.987	0.003	9.320	0.002	-	-	0.896	0.345	30.01	4e-8
4	4.296	0.038	4.534	0.033	0.896	0.345	-	-	21.10	4e-6
5	6.495	0.013	6.083	0.014	30.01	4e-8	21.104	4e-6	-	-

The results of the experiments can be summarized as follows: The first object in the rank is the 3rd one, but there is no significant difference between it and the following object in the rank, the 4th one. They are followed by the 1st and 2nd objects. There is no difference between them according to the opinion of the observers. The last object is the 5th object, it is the least preferable of the five objects and significantly worse than the others.

Our decisions may be refined as follows: we accept H_0 if the level of significance is more than 0.1, reject it if the level of significance is less than 0.01 and the cases when the level of significance is between 0.1 and 0.01 are considered border-line cases. These are also included in Table 5.

Table 5

Decisions at the standard significance level $\alpha=0.05$ (A- H_0 is accepted, R- H_0 is rejected) and the refined version (A- H_0 is accepted, R- H_0 is rejected, B-Border-line case)

Decision	$j=1$		$j=2$		$j=3$		$j=4$		$j=5$	
$i=1$	-	-	A	A	R	R	R	B	R	B
$i=2$	A	A	-	-	R	R	R	B	R	B
$i=3$	R	R	R	R	-	-	A	A	R	R
$i=4$	R	B	R	B	A	A	-	-	R	R
$i=5$	R	B	R	B	R	R	R	R		-

The refined evaluation of the results is the following: two main groups of the objects can be distinguished. The first group consists of the 3rd and 4th objects, the second one consists of the 1st, 2nd and 5th objects. The 3rd and 4th one are equal, and so are the 1st and the 2nd at any level of significance according to the opinions of the observers. The difference between the pairs 2nd and 5th, moreover 1st and 5th are on the border-line of the sensation. The same situation holds for the pairs 4th and 1st and 4th and 2nd. If the sample had been larger than the border-line cases could be decided about.

7 Comparison with the Results of AHP

As no theoretical justification of the existence of latent random variables with normal distributions is proved theoretically, we try to justify the results experimentally. For this purpose the results were compared with the ones coming from the other used statistical method. In order to check the rank, we performed the AHP method generally accepted in pairwise comparison. Number 1 is applied for the opinion “equally preferable”, number 3 for the opinion “more preferable” and number 5 for the opinion “much more preferable”, and inversely number 1/3 is used for the opinion “less preferable” and 1/5 for the opinion “much less preferable” in case of separate observers. The separate opinions are aggregated by taking geometric means. Using the matrix consisting of aggregated opinions, we

determined the normalized eigenvector belonging to the maximal eigenvalue and we obtained $\underline{v}=(0.184, 0.181, 0.253, 0.231, 0.150)$. The components of \underline{v} provide the AHP weights and it can be seen that they produce the same rank that was presented by our method. The vector \underline{v} has only positive components and their sum equals 1. To be able to compare them and the appropriate components of $\hat{\underline{g}}$, take the normalized vector

$$\left(\frac{\exp(\hat{m}_1)}{\sum_{i=1}^5 \exp(\hat{m}_i)}, \frac{\exp(\hat{m}_2)}{\sum_{i=1}^5 \exp(\hat{m}_i)}, \frac{\exp(\hat{m}_3)}{\sum_{i=1}^5 \exp(\hat{m}_i)}, \frac{\exp(\hat{m}_4)}{\sum_{i=1}^5 \exp(\hat{m}_i)}, \frac{\exp(\hat{m}_5)}{\sum_{i=1}^5 \exp(\hat{m}_i)} \right) \quad (5)$$

Its coordinates are close to the above AHP weights. This suggests that the AHP method may be in close connection with our presented method.

The AHP method is able to filter out those opinions which are inconsistent. Consistency is an important concept in AHP and there are different approaches in this area [17]. The advantage of this filtering is the usage of more reliable opinions, the disadvantage is the smaller sample size. In order not to reduce the sample extremely, we used those observations which have consistency index less than 0.3. The number of observers taken into account decreased to 34. The opinions, after aggregating them, are in Table 6. This table contains 340 judgments as opposed to the original 480, but these judgments are from reliable observers.

Table 6
Aggregate opinions of the reliable observers

$A_{i,j,f}$	$f=1$	$f=2$	$f=3$	$f=4$	$f=5$
$i=1, j=2$	5	9	15	5	0
$i=1, j=3$	4	16	6	6	2
$i=1, j=4$	2	12	15	4	1
$i=1, j=5$	5	4	7	9	9
$i=2, j=3$	8	9	14	1	2
$i=2, j=4$	3	11	17	3	0
$i=2, j=5$	3	7	9	6	9
$i=3, j=4$	2	8	15	9	0
$i=3, j=5$	3	6	4	13	8
$i=4, j=5$	4	2	15	8	5

After the computations based on these data, the AHP weights are $\underline{v}^*=(0.170, 0.183, 0.257, 0.240, 0.151)$. The estimated value of the parameter \underline{g} is $\hat{\underline{g}}^*=(0, 0.095, 0.404, 0.331, -0.136, 0.491, 2.595)$, which serves the same rank (3,4,2,1,5) as AHP weights. We computed the normalized exponential weights by

(5) and we obtained the vector (0.171, 0.188, 0.255, 0.237, 0.149), which is really close to $\underline{\nu}^*$, the maximum difference in the coordinates is 0.005. We can realize that this rank is slightly different from the one which was produced from all observations, actually the 2nd object is before the 1st one, but the equality of the two expectations is accepted in both cases. The levels of significance of the equality of expectations based on reliable opinions and the decisions can be summarized as follows:

Table 7

Significance levels using only reliable opinions and decisions using only reliable opinions (A- H_0 is accepted, R- H_0 is rejected, B-Border-line case)

	<i>j=1</i>		<i>j=2</i>		<i>j=3</i>		<i>j=4</i>		<i>j=5</i>	
	<i>A</i>	<i>dec.</i>	<i>α</i>	<i>dec.</i>	<i>A</i>	<i>dec.</i>	<i>A</i>	<i>dec.</i>	<i>α</i>	<i>dec.</i>
<i>i=1</i>	-	-	0.402	A	0.0004	R	0.004	R	0.230	A
<i>i=2</i>	0.402	A	-	-	0.007	R	0.038	B	0.042	B
<i>i=3</i>	0.0004	R	0.007	R	-	-	0.516	A	3e-6	R
<i>i=4</i>	0.004	R	0.038	B	0.516	A	-	-	4e-5	R
<i>i=5</i>	0.230	A	0.042	B	3e-6	R	4e-5	R	-	-

Comparing them to the decisions arising from the data without filtering in Table 5 we can realize that the results are very similar. Only 2 border-line cases remained. Two border-line cases become definite answers: from pairs 1st and 4th, 1st and 5th confirming the two groups mentioned in Section 6. Otherwise, there is no principal difference in the results whether we filter the opinions or not.

8 Experimental Results of the Survey

During the European research project (SSL4EU – Solid State Lighting for Europe) visual experiments were conducted at the University of Pannonia, where the optimal spectral power distribution of LED light sources was developed for home environment and fashion stores. In this part of the paper, the application of the mathematical method is demonstrated by the evaluation of a visual experiment on shop lighting. In order to present a realistic shop environment for the observers, the experimental room was equipped with four mannequins which were dressed with different clothes. Figure 6 shows the setup of the experimental room. Mannequins 1 and 2 can be seen on the left and mannequins 3 and 4 on the right of Figure 6. The different clothes worn by mannequins are the following: 1: green t-shirt, brown trousers of suit, 2: red t-shirt, blue jeans, violet belt, blue dress shirt, 3: white blazer, black t-shirt, turquoise trousers, yellow hat, 4: purple sweat-shirt, dark blue t-shirt, brown cord trousers.



Figure 6
Setup of experimental room

During the realization of light sources several photometric and colorimetric parameters and color quality metrics were used such as the Color Rendering Index ($CRI-R_a$) [18], the Color Quality Scale (CQS) [19], Feeling of Contrast Index (FCI) [20], Gamut Area Index, luminous efficiency or the Correlated Color Temperature (CCT) of the exited light. In addition, the R_9 value means the color rendering of saturated red color. The aim of the shop lighting experiments was to find an optimal light source spectrum for shop lighting by optimizing spectral distribution according to the FCI index. During the investigations five test light sources were developed. In Table 8 the first column (Test light ID) shows the code of the test lights.

Table 8
Summary of colorimetric parameters of the realized test lights investigated in the shop environment

<i>Test light ID</i>	<i>LED selection criteria</i>	<i>FCI</i>	<i>CCT [K]</i>	<i>Δuv</i>	<i>$CRI R_a$</i>	<i>R_9</i>	<i>CQS Q_a</i>
SS1	<i>Incandescent mimic ($R_a=97$)</i>	123	2900	-0.008	97	93	94
SS2	<i>High CQS Q_p value ($Q_p=96$, $R_a=80$)</i>	142	2947	-0.014	84	32	87
SS3	<i>$FCI = 110$, $R_a=82$</i>	107	2941	-0.014	78	15	75
SS4	<i>$FCI = 140$, $R_a=80$</i>	134	2920	-0.014	84	54	78
SS5	<i>$FCI = 150$, $R_a=80$</i>	151	2983	-0.009	85	-5	89

In order to find the preferred spectral power distribution (SPD) the presented paired comparison method has been applied during the visual experiments. Two SPDs (called “light source pair”) were changed five times at regular intervals before the observers evaluated their impressions. For the evaluation random lamp pairs had been determined from the set of five different test spectra and each spectrum was compared to the four other SPDs in the same group. SS1 is considered the 1st object, SS5 the 5th one. So the five optimized spectra resulted in ten paired comparisons. The observers’ task was to compare the two lights presented to them alternately every 20 seconds for 3 minutes, rate their visual experience for the given objects (different clothes) and fill in the questionnaire based on their visual impression.

At the end of the experiment sixty-three (63) observations were available to draw the conclusions from. The observers made their observations separately. Before the visual experiment the visual acuity of the observers was tested with the Kettesy reading test [21] (Hungarian version of the Snellen chart), and color vision was tested with the help of the Munsell Farnsworth 100 Hue test [22]. Only color normal observers were involved in the experiments.

Based on the observers’ judgment preference orders of test light sources for the different testing conditions were obtained. Besides the preference orders the similarity of the test lights has also been evaluated based on the significance value achieved by different light pairs. Three cases were distinguished: Two spectra were regarded as different, equal or border-line.

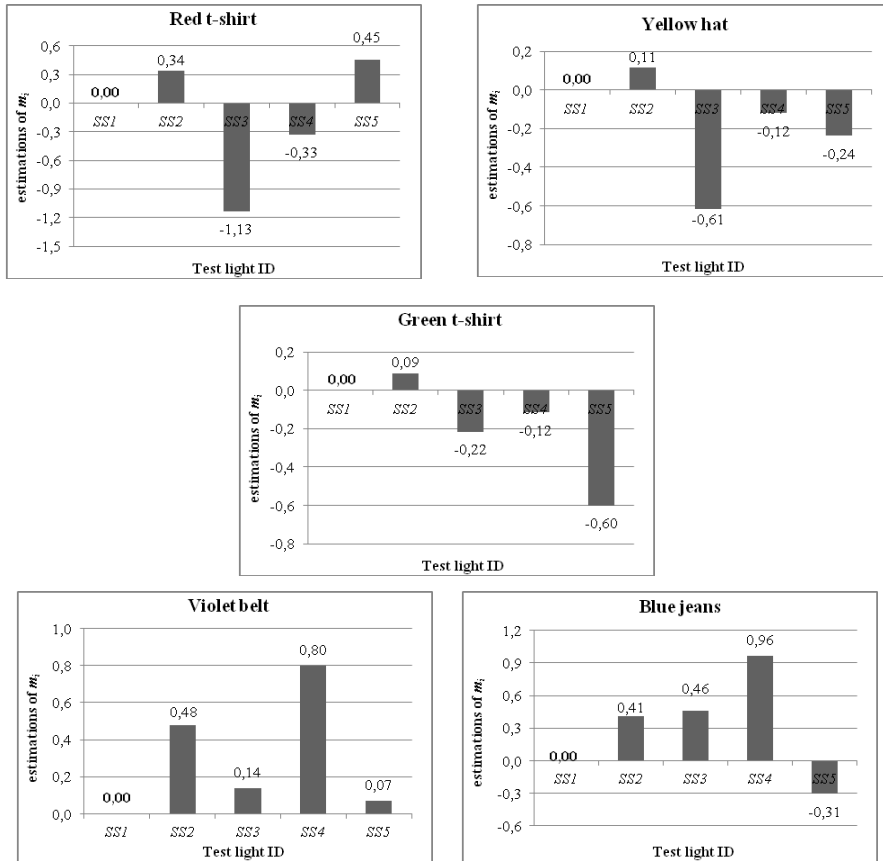
Although during the experiment the observers’ task was to evaluate thirteen different clothes under the light source pairs, but in this paper only results for five garments will be presented. These are the following: red t-shirt, yellow hat, green t-shirt, violet belt and blue jeans.

Based on the observers’ opinion the following sequences were obtained in case of these garments. At the ranking, the estimations of the m_i values were taken into account. Table 9 shows the ranking orders based on the values and diagrams in Table 10 summarize the sequences.

Table 9
Summarized table from the ranking orders

<i>Clothes</i>	<i>Preference</i>				
<i>red t-shirt</i>	5	2	1	4	3
<i>yellow hat</i>	2	1	4	5	3
<i>green t-shirt</i>	2	1	4	3	5
<i>violet belt</i>	4	2	3	5	1
<i>blue jeans</i>	4	3	2	1	5

Table 10
Estimated values of expectations



It can be seen that the preference of LED based lights depends on the color of the clothes. The first diagram in Table 10 shows that in case of red t-shirt the 5th illuminant was the most preferable one, but there is no significant difference between this light and the 2nd light source. Hence in case of the red – yellow and green clothes rather the 2nd test light source was perceived as the best. In case of the violet and blue garments rather the 4th was the best. In addition the observers least preferred the 3rd illuminant for the red and yellow clothes, while for the violet and blue garments the 1st and 5th light sources were preferred at least. The results were the same as those when the questions concerning vividness were evaluated.

Table 11

Decisions (A – equality accepted, R – rejected, B – border-line case)

<i>Shop lighting experiment</i>																	
<i>red t-shirt</i>						<i>yellow hat</i>						<i>green t-shirt</i>					
<i>SS</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>SS</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>SS</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
<i>1</i>	-	R	R	R	R	<i>1</i>	-	A	R	B	R	<i>1</i>	-	A	R	B	R
<i>2</i>	R	-	R	R	A	<i>2</i>	A	-	R	R	R	<i>2</i>	A	-	R	B	R
<i>3</i>	R	R	-	R	R	<i>3</i>	R	R	-	R	R	<i>3</i>	R	R	-	A	R
<i>4</i>	R	R	R	-	R	<i>4</i>	B	R	R	-	A	<i>4</i>	B	B	A	-	R
<i>5</i>	R	A	R	R	-	<i>5</i>	R	R	R	A	-	<i>5</i>	R	R	R	R	-

<i>Shop lighting experiment</i>											
<i>violet belt</i>						<i>blue jeans</i>					
<i>SS</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>SS</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>
<i>1</i>	-	R	B	R	A	<i>1</i>	-	R	R	R	R
<i>2</i>	R	-	R	R	R	<i>2</i>	R	-	A	R	R
<i>3</i>	B	R	-	R	A	<i>3</i>	R	A	-	R	R
<i>4</i>	R	R	R	-	R	<i>4</i>	R	R	R	-	R
<i>5</i>	A	R	A	R	-	<i>5</i>	R	R	R	R	-

Considering the similarity of the light sources in case of the red t-shirt the 2nd and 5th light sources were perceived the same and the others were different based on the observers' opinion. For the yellow hat next to the 1st and 2nd light illuminants the 4th and 5th show similarity, while between the 1st and 4th light source the difference moves at the border of the demonstrability. In case of the green t-shirt less difference can be seen: the 1st illuminant shows similarity with the 2nd test light and the 3rd illuminant shows similarity with the 4th light source. The difference between the 1st – 4th and 2nd – 4th illuminants is on the borderline.

For the violet belt the 1st – 5th and the 3rd – 5th light sources were perceived as similar and the difference between the 1st and 3rd illuminants moves at the border of the demonstrability. In case of the blue jeans significant difference can be seen between the light sources. Only the 2nd test light shows similarity with the 3rd illuminant. A more detailed presentation of the results was published in [2].

Conclusion

A statistical method was elaborated herein for ranking spectral power distributions (SPD) based on subjective points of view. Pairwise comparisons were performed with five options in judgment. The evaluation method was improved and a maximum-likelihood estimation was performed by applying the R statistical package. Not only ranking has been developed and compared to the results of the AHP method, but the equality of the object characteristics has also been tested.

Differences are often traceable on the basis of the opinions of 60 observers. A possible connection between the AHP weights and the estimated expectations is presented. The method was successfully applied in choosing light sources for home lighting and shop lighting [1, 2] and can be applied in the case of further choices based on subjective points of view. The results of the experiments depend on the dominant color of the illuminated objects.

Acknowledgment

This research was supported by the EU FP7 project SSL4EU (Solid state lighting for Europe), grant number 282760.

References

- [1] F. Szabó, R. Kéri, J. Schanda, P. Csuti, É. Mihálykó Orbán: A Study of Preferred Colour Rendering of Light Sources: Home Lighting, Lighting Research and Technology, 2015 47: 165-182, Online ISSN: 1477-0938 Print ISSN: 1477-1535
- [2] F. Szabó, R. Kéri, A. Wilm, J. Schanda, P. Csuti, E. Baur: A Study of Preferred Colour Rendering of Light Sources: Shop Lighting, Lighting Research and Technology, in press, Online ISSN: 1477-0938 Print ISSN: 1477-1535
- [3] J. Schanda, P. Csuti, F. Szabó: Colour Fidelity for Picture Gallery Illumination, Part 1: Determining Optimum LED Spectrum, Lighting Research and Technology, in press, Online ISSN: 1477-0938 Print ISSN: 1477-1535
- [4] J. Schanda, P. Csuti, F. Szabó, P. Bhusal, L. Halonen: Introduction to a Study of Preferred Colour Rendering of Light Sources, Lighting Research and Technology, 47:28-35, 2015
- [5] M. S. Islam, R. Dangol, M. Hyvärinen, P. Bhusal, M. Puolakka, L. Halonen: User Acceptance Studies for LED Office Lighting: Lamp Spectrum, Spatial Brightness and Illuminance Level, Lighting Research and Technology, 47: 54-79, 2015
- [6] K. R. Gegenfurtner, L. T. Sharpe: Color Vision from Gene to Perception, Cambridge University Press, 1999
- [7] W. G. K. Backhaus, R. Kliegl, J. S. Werner: Color Vision Perspectives from Different Disciplines, Walter de Gruyter, 1998
- [8] L. Saaty: The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, McGraw-Hill International Book Co., New York, 1980
- [9] O. S. Vaidya, S. Kumar: Analytic hierarchy process: An Overview of Applications, European Journal of Operational Research, 169: 1-29, 2006

- [10] O. Perron: Zur Theorie der Matrices, *Mathematische Annalen*, 64(2):248-263, 1907
- [11] L. L. Thurstone: A Law of Comparative Judgment, *Psychological Review*, 101(2): 266-270, 1994
- [12] F. Mosteller: Remarks on the Method of Paired Comparison I. The Least Squares Solution Assuming Equal Standard Deviations and Equal Correlations, *Psychometrika* (16)1: 3-9, 1951
- [13] T. Pfeiffer, X. A. Gao, A. Mao, Y. Chen, and D. G. Rand: Adaptive Polling for Information Aggregation, In the Proceedings of the 26th AAAI Conference on Artificial Intelligence (AAAI '12) 2012
<http://www.eecs.harvard.edu/econcs/bib/author.html>
- [14] S. S. Wilk: *Mathematical Statistics*, New York, John Wiley, 1962
- [15] F. T. Móri, J. G. Székely: *Multivariate Statistical Analysis*, Műszaki Könyvkiadó, Budapest, 1986 (In Hungarian)
- [16] R Core Team: *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria, ISBN 3-900051-07-0, URL <http://www.R-project.org/> 2012
- [17] J. A. Alonso, M. T. Lamata: Consistency in the Analytic Hierarchy process: a New Approach. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 14: 445-459 2006
- [18] Commission Internationale de l'Eclairage (CIE): *Method of Measuring and Specifying Color Rendering Properties of Light Sources*, CIE Publication 13.3, Vienna: CIE, 1995
- [19] W. Davis, Y. Ohno: Color Quality Scale, *Optical Engineering* 49: 033602, 2010
- [20] K. Hashimoto, T. Yano, M. Shimizu, Y. Nayatani: New Method for Specifying Color-Rendering Properties of Light Sources based on Feeling of Contrast, *Color Research and Application*, 32: 361-371, 2007
- [21] Webbeteg. Testing visual acuity. Retrieved 14 January 2015 from http://www.webbeteg.hu/cikkek/szem_betegsegi/3244/lataselesseg-vizsgalat
- [22] D. Farnsworth: *The Farnsworth-Munsell 100-Hue Test for the Examination of Color Discrimination*, Revised 1957; Baltimore, MD: Munsell Color Company

The Possible Success Factors of Introduction of CRM System at Hungarian SMEs

Regina Reicher¹, Nándor Komáromi², Ágnes Szeghegyi¹

¹Óbuda University, Keleti Faculty of Business and Management, Institute of Enterprise Management, Tavaszmező u. 17, H-1084 Budapest, Hungary
reicher.regina@kgk.uni-obuda.hu; szeghegyi.agnes@kgk.uni-obuda.hu

²Szent István University, Faculty of Economics and Social Sciences, Institute of Business Studies, Péter K. utca 1, H-2100 Gödöllő, Hungary
komaromi.nandor@gtk.szie.hu

Abstract: The information technology projects within companies often end with failure. It may be due to various reasons, but the human factor almost always can be blamed. The organizations, as groups or staff communities, frequently resist change and the introduction of CRM systems can lead to significant corporate changes.

A smaller team should participate in the selection and implementation of a CRM IT system. Our research focuses on the competencies required in the course of an implementation and the impact they may have on the decisions, within the process. We tried to explore the possible correlation, with the “index of success”, if the stakeholders in the implementation can be arranged in well-defined segments, on the basis of specific factors.

According to our results, the pairing specific factors can lead to a more successful project implementation and it is worth priority consideration, as the main factors when setting up the team.

Keywords: CRM implementation; CRM selection; factors affecting successful implementation; SME

1 Introduction

An organization is operated through human activities. The people working in the organization need information for their activities, as well as, for the coordination and harmonization of their cooperation. A basic objective for companies and organizations is to make a profit by fulfilling the needs of the consumer. This basic objective defines which consumers, which of their needs can be satisfied and with what kind of process, internal operation and environmental relations. [5]

Many papers written in the recent years indicate that only 30% of organizations introducing a CRM technology achieved some improvement in corporate performance. The research made by Chang et al has proved that the purchase of CRM technology is necessary but not sufficient condition of successful CRM implementation. [4]

Therefore, we regarded it necessary to examine how the two participants in the implementation, namely the supplier and the purchaser, manage the process. What are the competencies of those who participate in the project on behalf of the organization? How these competencies complement each other, how they affect the process of selection and implementation? Szabó reveals, in a research paper, that the innovation activities of the Hungarian SMEs lag behind and need significant improvement compared to those in other countries. [10]

It is inevitable for the introduction of CRM systems that the organization, itself become, client-oriented. It means that the organizational hierarchy should be considerably different from a traditional organizational structure. According to Rust [7], the responsibilities should be re-defined because it is important that everybody is completely aware of their tasks. A new position is announced, namely the client manager, who has operative responsibilities with an appropriate authorization. The work of client manager includes strategic planning, fulfillment and monitoring of client-side functions. It is especially important to modify the organization structure which obstructs the information flow.

2 Strategy

Of course, the new organization will not be self-established. An organization very rarely wants to change itself. These types of organizational restructuring occur mostly due to external forces or pressure from above. In this kind of a radical change, the development and implementation of a new strategy requires set up of a new organizational structure and the introduction of a new corporate culture and development of a new incentive system. These are the tasks of the top management.

The appropriate handling of possible negative reactions, should always be given attention, in the course of planning and managing the organizational development project. The project will only be successful if the Chief Executive or the management board, adjusts to the corporate targets, in their attitudes.

“...if the focus of the operation of a company is to be changed so drastically, it should be accompanied with the revision and – if necessary – the restructuring of the staff motivation system. First it should be examined what kind of staff competencies are needed in the new organization. If it is clear, we should examine how we can achieve them, considering, for example, the development of

appropriate recruitment processes, the career planning of staff as well as the optimized introduction of different – financial and other – motivation tools.” [6]

The adequate internal motivation of staff guarantees that they perform their jobs with maximum efficiency. The excellent professional competence of colleagues or merely creating appropriate physical and environmental conditions is not enough.

The internal processes, including the process of client management, will change in the restructured organization.

It is extremely important that the company clearly focuses its CRM implementation, from the very first moment, carefully chooses the segment or the function where the first steps are to be made in order to reach the highest possible returns. Naturally, it should also be considered that the positive experiences connected with the implementation significantly improve the outcome of future projects or the introduction of other functions in other segments within the company. (Figure 1) [8]

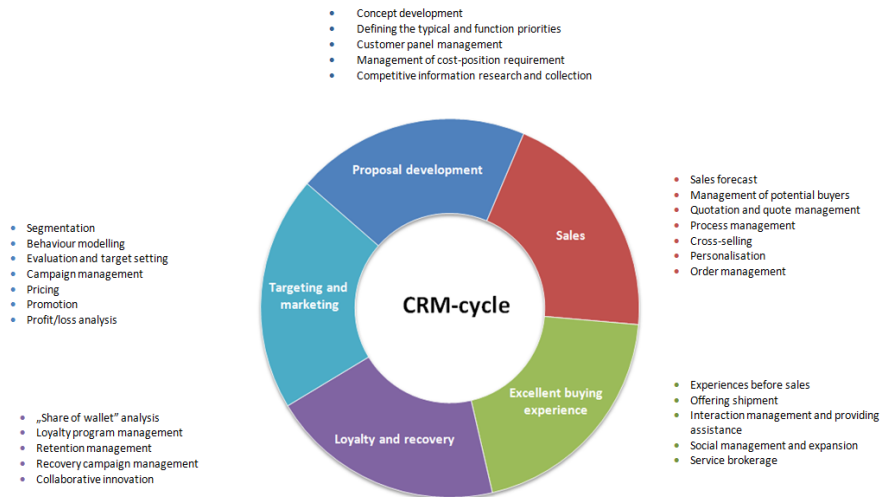


Figure 1

Customer relationship cycle source: [8]

Bűdy discusses ten critical success factors which may have key roles in the introduction of CRM. Among these he puts the definition of functions to be automatized in the first place. The CRM system will not be efficient if the audit is missing or inadequately performed. [3]

According to him, the success factors also include the unconditional attainment of management support, the thoughtful selection of applied technology, the training of users using the system, motivation of staff and appointing the person who are responsible for the operation of the system.

The operation of every organization – of all sizes – largely depends on its Chief Executive. Thus, the appointment of the head of CRM is also crucial from the aspect of a successful project. The head of the program should be trustworthy and supported by everybody in as much as possible. They should be able to represent the interests of staff and the CRM project alike in the communication with the senior management and should be able to enforce the interests of the company and the CRM project against the subordinate staff. They should make quick and firm decisions and their expertise cannot be questioned.

Tomka and Bögel [11] also regarded it undisputable, that the information technology, significantly contributed to the transformation of knowledge management be in an independent area. But they warn to identify knowledge management with information technology management or IT applications. The knowledge projects cannot be purely information technology projects. In their opinion, these projects can be successful, if the technical and the human-organizational sides are equally considered.

3 Organization Development and Management Roles

A company may regard the development of its organization important for many reasons. It may be exposed to several impacts which cause different changes in the corporate life. These changes, possibly crisis situations may compel the company management to rethink the structure and strategy of the organization. The introduction of a CRM strategy and the development of its information technology support is also such kind of a change in the life of an organization.

According to Tomka and Bögel [11] the most important issue of change management is timing. The experiences prove that people, thus the staff of the organization, too, are reluctant to accept changes. Until they do not feel the danger of losing their job or other factors, they will not be stimulated to change. The change, however, forced by an external pressure might be too late for the organization. An economic crisis, for example, may considerably narrow the room for any maneuvering for the company, thus the number of possibilities will be reduced. Moreover, in an extreme case, like this, the executives of companies will probably invest all their energy into the management of actual problems.

Angyal says that one of the main features of a leader is that they deal with people. Their task is to convince the staff to act and make decisions for the sake of the organization, regardless of their own motivations. [1]

Reviewing the above theories and research, it can be concluded that those companies are successful today where the organization proceeds along a well-defined strategy, the members of the organization are committed and the executives are leader-type personalities with strategic attitudes.

A company cannot responsibly rely on the decision of one person, in case of such a far-reaching decision. Moreover, the wide range of professional expertise is inevitable not only in the field of information technology, but also in economic and organizational structure, as well as, production technology.

In case of software purchase, the organizational structure of the decision-making group is a team organization which is typically “a task-oriented and autonomous unit consisting of people of different positions from different professional fields of the company. It is set up to carry out temporary or permanent tasks.” (Presentation of Dr. Ferenc Nemes, 2009)

The members of the group work towards a common goal during the project. It is worth placing the members of the group in physical proximity to each other for the time of the common work in order to ensure efficient flow of interaction and communication. Naturally, the professional competencies in the team are adjusted to the target of the project. Therefore, our examination aims to survey the qualities of colleagues participating in the implementation as well as their attitudes in connection with CRM information technology implementation.

Our research was carried out with the help of cluster analysis based on principal component analysis.

4 Cluster Analysis

Cluster analysis is the whole family of those techniques, which divide large number of respondents into smaller groups, by ensuring the homogeneity of attitudes, experiences, preferences and/or behavior of the group members. [9]

The point in this segmentation method is that the differences between respondents are small within the cluster but the differences between the groups are large.

We tried to form the clusters along the principal components and examined which principal component is accepted or rejected by which segment.

As the result of the principal component analysis, three well-defined components were set up which had special significance for the respondents and belonged together according to their evaluation.

The elements of the strategic principal component included the mapping of corporate maturity, the rationalization of processes, the elaboration of customer management strategy, accurate definition of needs, permanent management support and exact exploration of financial possibilities.

The technological principal component covered the appropriate test run during implementation, the definition of authorization system and the use of faultless database.

Finally, the elements of the human principal component were the involvement of independent consulting agency, information service to staff, permanent management feedback, continuous supplier system control and customer meetings, exchange of experiences organized by the supplier.

The attitudes of respondents can be examined hereinafter along these components.

The cluster analysis was made with K-Means Cluster process which starts from K number of predetermined clusters. The program assigns a center point to each cluster and then by using the square of Euclidean distance, those elements are assigned to these centers which are the closest to them. Therefore the groups are formed by the program in a way that they are as far from each other as possible but those in the same cluster are as close to each other as possible. Thus they can be separated easily on the basis of their characteristics.

Table 1
Cluster analysis – cluster centers

	Cluster		
	1	2	3
strategia s1	-0.60571	-5.08008	0.52909
technologia t1	-0.59972	-4.42051	0.51585
human h1	-0.85231	0.06744	0.64956

Source: own research

Our intention was to determine three clusters along the three principal components, thus the first analysis focused on this. The table of the ultimate cluster centers (Table 1) demonstrates the attitudes of respondents in each cluster.

It is obvious that the group in the 1st cluster rejects all the components while those belonging to the 3rd cluster have a positive attitude to all the components. The members of the 2nd cluster prefer – although weakly - the elements of human component, while they reject the elements of strategic and technological component.

The ANOVA table (Table 2) is not the table of a typical variance analysis. The value of F indicates the strength of each component in the formation of the cluster. The significance level in this case is 0.005, when the participation can be regarded significant.

Table 2
Cluster analysis - ANOVA

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
strategia s1	34.181	2	0.497	132	68.738	0.000
technologia t1	30.313	2	0.556	132	54.532	0.000
human h1	37.102	2	0.453	132	81.901	0.000

Source: own research

Finally it was examined how many respondents belong to each cluster (Table 3). It can be seen that all the respondents could be assigned to one of the groups in the course of the analysis. There is only one respondent in the 2nd cluster, thus this cluster analysis could not be accepted because it would have meant that the human aspect received too much importance. This respondent is considerably different from the others and the variable formed by him is inadequate for further analysis and would distort the result of the examination.

Table 3
Cluster analysis – Number of Cases in each Cluster

Cluster	1	58.000
	2	1.000
	3	76.000
Valid		135.000
Missing		0.000

Source: own research

The analysis was continued by changing the number of clusters on the parameter of cluster analysis. It was expected from this step that the change of cluster figures requires new cluster centers thus the distribution of respondents would be more proportional in the clusters. That one particular respondent, however, had to be placed in an independent cluster again. The checking of this was made by selecting the data file on the basis of the cluster. Since the respondent in the 18th record could not be fit into the cluster structure, he was taken out from the data set with a mark and thereafter the cluster formation was made without him.

The cluster centers created this way are in Table 4.

Table 4
Final cluster centers

	Cluster		
	1	2	3
strategia s1	-0.29956	-0.60648	0.50706
technologia t1	0.47076	-1.28937	0.48791
human h1	-0.97067	-0.75314	0.80623

Source: own research

31 persons, that is 23.1% of the respondents, are put in the first cluster. 34 people belong to the second cluster, that is 25.4% of the respondents. The third cluster includes 69 persons, that is 51.5% of the total number of respondents. All the respondents participating in the analysis were ranked somewhere.

The ANOVA table indicates significant participation in case of all the principal components. The value of F is the lowest in case of the strategic component which means that this component is the weakest in the cluster formation. It is evident that along the principal components, similar F values belong to significant difference in two cases out of the three segments while in one case the F value is lower than these. It means that the technological and human components among the dimensions participated in cluster forming to a similar extent while the strategic component had weaker influence on cluster forming. (Table 5)

Table 5
Significance analysis of cluster analysis

	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
strategia s1	16.418	2	0.574	131	28.614	0.000
technologia t1	39.837	2	0.264	131	150.661	0.000
human h1	46.672	2	0.310	131	150.402	0.000

Source: own research

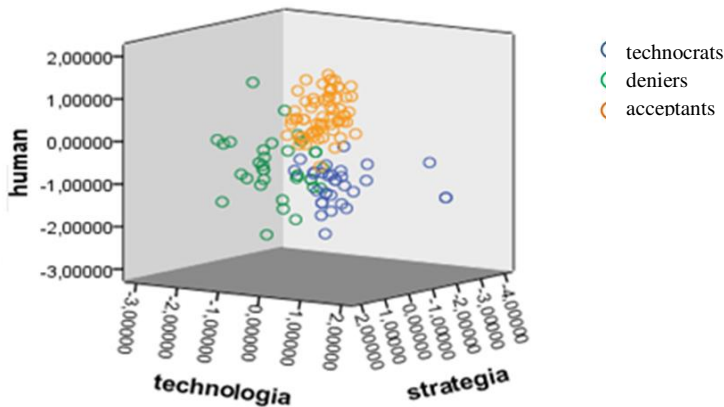


Diagram 1
Cluster depiction - 3D Scatter

Source: own research

The 3D Scatter diagram (Diagram 1) clearly demonstrates the three separate segments. The technocrat respondents are located on the negative side of strategic (Z axis), while they are on the positive side from technological aspect (X axis). The deniers are grouped in the negative end of all the three axes, while the acceptants are on the positive ends. It is even more obvious from the cluster matrix depiction, where every element describes respondents only in relation to 2 axes at a time. (Diagram 2)

The segments created on the basis of cluster centers can be characterized on the basis of principal components as follows. The respondents belonging to cluster 1 are the **technocrats**. The technological support and technical background is the most important for them. They strongly deny that human factors may affect success and they do not consider strategic steps important, either, although to a smaller extent. 90.3% of the members of this cluster are users and only 9.7% are experts. It is 26.9% of all the users, that involve IT staff in the selection regardless of the special field of the IT staff. In practice it means that mostly the system administrators got this task. As regards software selection, the key aspect is the comparison of hardware and software elements. These users mostly make decisions by themselves. 85.7% of them finds the supplier of the chosen software through the internet.

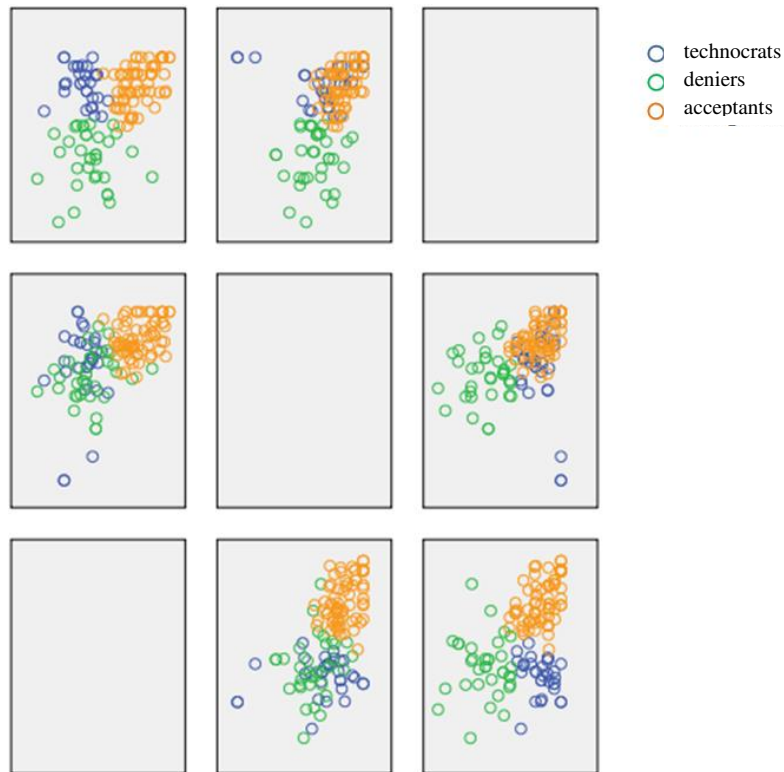


Diagram 2
Cluster matrix

Source: own research

The IT specialists have more information about the actual objectives of the software therefore they are mostly put in the other two clusters. Only 10% of them belong to this cluster (Table 6). These specialists have a few years of experience and have tracked the implementation of maximum 2 different software packages. They set the success indicator of their implementation projects to a significantly low level and described them as failures in a ratio of 50% or even higher.

Table 6
Respondents in the clusters

			Respondent		Total
			1	2	
Cluster 1	Count		28	3	31
	% within cluster		90.3%	9.7%	100.0%
	% within respondent		26.9%	10.0%	23.1%
	% of Total		20.9%	2.2%	23.1%
2	Count		24	10	34
	% within cluster		70.6%	29.4%	100.0%
	% within respondent		23.1%	33.3%	25.4%
	% of Total		17.9%	7.5%	25.4%
3	Count		52	17	69
	% within cluster		75.4%	24.6%	100.0%
	% within respondent		50.0%	56.7%	51.5%
	% of Total		38.8%	12.7%	51.5%
Total	Count		104	30	134
	% within cluster		77.6%	22.4%	100.0%
	% within respondent		100.0%	100.0%	100.0%
	% of Total		77.6%	22.4%	100.0%

Source: own research

Members of cluster 2 are the **resistants**. They under-evaluated the features of all the three components. They reject the technological features the most and have similar relation to the other two components, too. 23.1% of all the users belong to this group, which is 70.6% representation in the cluster. They probably buy the system, then operate it on a hit or miss basis. They do not make preparations, do not „make it a big deal“. 54.2% of them consult less than three times before the implementation. They see the solution of all the problems in the introduction of a CRM system. They mostly make their decisions alone – it makes up to 40% of users belonging to the cluster. Their implementation projects end with failure in most of the cases because the software does not solve their problems, rather create some new ones. These users significantly do not feel the emergence of unexpected costs. 95% of respondents belonging to this group collected the information from the competitors and introduced the software they saw there – thinking that „if it is good for them, would be good for us, too“. 50% of the cluster

members marked easy use as a decisive factor in their choice. 75% of users belonging here searched the internet and found the supplier there.

33.3% of experts were put in this cluster. These experts probably sell software solutions on the market which belong to the so-called solution-in-a-box category and follow the “Take it and use it” principle. The “box” solutions among the cloud-based systems are also in this group. The user support often consists of “mass” courses on one or two occasions where general guidelines for use are given to the purchasers in the frames of a common presentation. They underline the immediate applicability of the software and promise immediate solution by uploading the data in the system. 80% of these experts participated in the implementation of three or less different softwares and only 20% of them had 8-10-year experiences. At least 50% or more of their implementation projects were successful.

The members of the 3rd cluster are the **acceptants**. They have a positive attitude towards all the three principal components. Human elements are far the closest to them and they attach similar values to the other two components. 50% of the users belong to this group which means 75.4% share in the cluster. They are probably those respondents who try to make decisions after careful preparation but do not weight the tasks and do not set an order of priorities. Their attention is too divided, they may break down due to the diversity of tasks. They are lost in the criteria system of the software selection and finally they decide on the basis of criteria which are not necessarily professional or do not meet their objectives. 50% of the respondents make team decisions and 60% of them consult with the supplier more than 3 times before making a choice. 86.4% of the cluster members significantly indicated the tracking of internal processes as the reason for the investment. They probably regard the internal processes too complicated, but there is a significant dispersion regarding their opinion about the involvement of external consultants. Therefore their implementation projects can also lead to the feeling of failure. 100% of the cluster members make their decisions on the basis of an offer given by another supplier. 62% of them reviewed the offers of 2-5 suppliers, while 15% collected offers from more than 5 suppliers.

This cluster includes 56.7% of the experts and presumably, the representatives of medium and large systems also belong here. Those specialists are here who have experiences from the implementation of 4-5 different systems and 55.55% of those, with 8-10 year experience. They regard the success of their implementation projects significantly good ($p=0.003$) and successful, in a ratio of 75%.

Conclusions

The results of our survey have proven that clearly distinguishable groups can be identified along the factors of preparation and implementation. The differences between the segments can be clearly characterized. The members of each segment were examined on the basis of their role in implementation. Thus, the expert members could be characterized separately on the basis of their success and

experience, while the members of the purchasing side could be described on the basis of management decision and software selection criteria system.

By reviewing the information system implementations it can be concluded that the introduction of CRM systems was mostly accompanied by the sense of failure both on behalf of the supplier and the purchaser. The number of implementations, however, do not decline, in spite of the fiasco feeling and the experts have hopes for slow growth due to the recovery after the economic crisis. In order to avoid the implementation failure, however, there are some serious tasks to be performed by the supplier as well as the purchaser.

It is very important that the executives of the companies do not regard the purchase and implementation of the system as failure or an “unnecessary waste of money”. If the company is not mature enough in terms of organization and/or information system, it is often enough to form a new organizational structure, to apply a well-defined customer strategy in order to make the management feel the positive impacts.

On the basis of our quantitative research it can be concluded that the software supplying side is not fully aware of the motivations and demands of purchasers. The suppliers develop the ideas concerning the customers and hypotheses concerning their decisions on the basis of a general knowledge about consumers.

Our research has proved that the information technology background of purchasers is not adequate. Often the strategic preparedness is also missing for the implementation of the CRM system, therefore the purchasers do not define their needs precisely, they do not set objective criteria system regarding the software to be implemented. The implementation is not treated like a project, the methodological support is expected from the supplier.

In the further part of our examination, principal component analysis was applied for the evaluation of opinion of respondents concerning the preparation and implementation. The importance of each task was evaluated on a scale from 1 to 10, where 1 meant not important at all and 10 was the most important.

The explained variance of principal components was roughly proportional. The results of the survey, of course, cannot be regarded as generalized conclusions for the whole domestic market due to the deficiencies of sampling but the main trends are obvious on the basis of replies received from suppliers and purchasers.

The next step was to examine the ratio of the two responding groups – expert and purchaser – in every cluster. It was concluded that both the experts and the users were represented in all the three clusters. Then, we analyzed what common features can be found regarding the members of groups standing in the two different sides but within one cluster. According to our examination, some of the characteristics of users and experts could be well defined in the three clusters, but there were strong differences between the groups.

It was proven by our research, that the purchasers, can cope with the lack of serious professional expertise. The methodological deficiencies of suppliers do not help the purchasing companies to solve this problem. Moreover, the supplier side has only a superficial knowledge concerning the motivations and needs of implementing side, therefore the possibly existing methodology does not necessarily put the emphasis on the adequate points. Since we tried to map both sides in our research, we drafted our recommendations separately for the supplier or expert side and separately for the purchaser side.

The outcomes of principal component and cluster analysis have highlighted that the professionals have different attitudes and they regard different areas important. Following the survey of existing staff it is worth setting up expert pairs who can help the implementation projects by complementing each other. Thus, none of the areas will dominate and every task will have an appropriate emphasis.

In regards the purchaser side, the software is selected on the basis of the decision of one person. The disadvantages of this are highlighted by the results of the research. Setting up a professional team would eliminate these drawbacks and the risks of “one-person” decision. The members of the team should be selected on the purchaser side on the basis of the preferences thus it is possible to set up a professional staff who are competent to manage a full implementation project.

The aim of using a CRM system is to classify the information flowing in through different channels and to present the information in a unified way, broken down by customers. Thus, the company is able to define the value of its clients and make the management of primary clients even more efficient. Although the consumption slowly increases due to the economic recovery but it will probably be a slow and lengthy process. The power relationships will change among the economic actors and new centers of gravity will emerge, for example, China or India. There will be a strong battle to keep market share and the emergence of new product categories will be especially important. [2]

These two strategic objectives will definitely target the retention of customers and providing service, at the highest possible standard. Customer relationship marketing and CRM strategy are excellent tools in these efforts, while the information technology support can help to perform efficiently and precisely. The technical knowledge of CRM systems can definitely support the comprehensive realization of customer strategies for companies.

References

- [1] Angyal Á. (1999) *A vezetés mesterfogásai*, Kossuth Kiadó, Budapest, p. 254
- [2] Beinhocher E.-Davis I.-Mendoca L. (2009) *Stratégia az új világban*, 10 trend, amelyre figyelünk kell, *Harvard Business Review* XI. évf. 2009/11 pp. 45-51

- [3] Bűdy L. (2011) A CRM lehetőségei a nagyvállalati gyakorlatban, Marketing & Menedzsment XXXV. évf. 2001/1 pp. 25-29
- [4] Chang W.-Park J. E.-Chaiy S. (2010) How does CRM Technology Transform into Organizational Performance? A Mediating Role of Marketing Capability, Journal of Business Research 2010/63 pp. 849-855
- [5] Chikán A. (2003) Vállalatgazdaságtan, AULA Kiadó, Budapest
- [6] Erdélyi E.-Kovács. B.-Merényi A.-Számely É. (2006) Experience of the Best Practice in CRM Implementation in Industry, T-Mobile, Telecom Hungary XVII. évf. 2006/3 pp. 16-23
- [7] Moorman C.-Rust R.-Bhalla G. (2010) A marketing újragondolása, Harvard Business Review XII. évf. 2010/5 pp. 42-50
- [8] Rigby D. K.-Ledingham D (2005) A helyes CRM, Harvard Business Review VII. évf. 2005/3 pp. 34-43
- [9] Scipione P. (1994) A piackutatás gyakorlata, Springer Hungarica Kiadó, Budapest
- [10] Szabó-Herman (2014) Productive Entrepreneurship in the EU and Its Barriers in Transition Economies: A Cluster Analysis, Acta Polytechnica Hungarica XI. 2014/6 pp. 73-94
- [11] Tomka J.-Bögel GY. (2010) Vezetés egykor és most, Nemzeti Tankönyvkiadó, Budapest

Determination of Recent Concentration of DDT and its Metabolites in Breast Milk in the Teaching of Behaviors of Persistence Organic Compounds

Zoltán Juvancz¹, Edina Garai¹, Loránt Szabó¹, Rita Boda-Kendrovics¹, Gabriella Köteles-Susztér²

¹ Department of Environmental Engineering, Óbuda University, Doberdó út 6, H-1034 Budapest, Hungary, juvancz.zoltan@rkk.uni-obuda.hu, szabo.lorant@rkk.uni-obuda.hu, bodane.rita@rkk.uni-obuda.hu

² Wessling Hungary Ltd. Fóti út 56, H-1047 Budapest, Hungary, suszter.gabriella@wessling.hu

Abstract: The problem of the persistent organic pollutants (POP) is an important part of the education program of Environmental Studies. The literature data refer several unwanted side effects of the intensive use of DDT. On the other hand the widely spread malaria epidemic infection makes the use of DDT necessary even today. The occurrence of DDT and its metabolites is a good representative of the persistency of such pollutants in the human breast milk. The samples were donated by university students and young teachers. This way the students could get personal involvement of the topic and measurements. The conventional and QuEChERS sample treatments were applied and their effectiveness were compared. GC-ECD instrumental analyses were used with parallel columns to demonstrate the selectivity and sensitivity of the required analysis. The results demonstrate the presence of DDE traces in breast milk of the majority of Hungarian mothers, even after the agricultural use of DDT was banned in 1968. No fresh DDT pollution was recognized in the tested samples. Correlations were established among the DDE contents of the breast milk samples and the ages and weights of the tested mothers. The measurements also show the persistency and biomagnificational feature of DDT. The educational aspects of each step of the applied procedures are emphasized in this paper. The analytical processes allow a deep insight for the environmental analysis for environmental engineering students. These offer a manual and theoretical practice with real samples, for improving the environmental attitudes.

Keywords: DDT and its metabolites; human breast milk; education of features of POPs

1 Introduction

The DDT (dichlorodiphenyltrichloroethane) was synthesized in 1874, and it was applied as pesticide since 1939. The worldwide production amount of DDT exceeded the 2.6 million tons, from 1950 to 1993, which is the largest quantity among the pesticides [1]. In Hungary, approximately 40 000 tons of DDT were used between the 1945-1966 period [2]. The unwanted effects of DDT and its metabolites resulted in the ban of the use of DDT for agricultural use in the vast majority of countries [3]. It is worthy to note that Hungary was the first country, which withdrew DDT from agricultural use in 1966 [2]. On the other hand the DDT remain in use as indoor DDT spraying against the malaria epidemic cases, because it is the most effective material against malaria transmitting insects (malaria mosquito anopheles) [4,5]. The analysis of DDT and other POP compounds are an important part of the knowledge of environmental engineering B.Sc. students.

The chemical structure of DDT and its main metabolite are in (Fig. 1) [6].

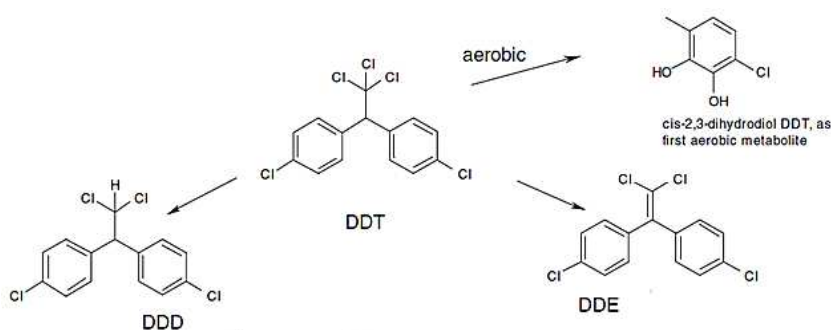


Figure 1

Structure of DDT (1,1,1-trichloro-2,2-di-(4-chlorophenyl)ethane) and its main metabolite DDD and DDE [6]

The DDT has low volatility (vapor pressure 2.53×10^{-5} Pa at 20°C) and lipophilic character (practically insoluble in water). These data suggest that the DDT and metabolites reach the human body through the food chain, with the exception of the direct inhalation of sprayed aerosols as mentioned in the literature in several times [2, 7]. DDT has very high persistency with 3-15 years half-life in soil, and DDE has even much stronger persistency than DDT [8, 9]. The high DDE/DDT ratio show old pollution, but low DDE/DDT ratio is evidence of recent DDT pollution [9]. The enantiomer ratios of *o,p*-DDE also provide information of origin of pollution [10].

The DDT is very effective insecticide, having neurotoxic (sodium channel opening) effect in insects [11]. The DDT had a very high popularity because it seemed to be a very effective pesticide and harmless for warm blooded animals.

Later several pests became resistant against DDT, and serious unwanted side effects emerged for fishes and warm blooded animals [11, 12]. The most shocking observations were written for the public in the “Silent Spring”, the book of Rachel Carson [12]. The facts of this book help to improve the environmental awareness. Topics of the book are partly valid even recently, therefore is an important literature for students.

The DDT has tumorigenic, neurotoxic, estrogenic endocrine disruptive effects for the warm blooded animals and humans [11, 12, 13, 14, 15]. One of the most dramatic symptoms was the egg thinning of predatory birds, which was the reason for drastic decline of predatory birds in several areas [13, 14]. The estrogenic effects of DDT caused a drastic shift of sex ratio of gulls toward the female [15], therefore often two females nested together. Not only the DDT, but their main metabolites show the toxic effects. DDE proved more toxic than DDT in several cases. This example demonstrates well, not only the mother compounds, but their metabolites have toxic effects in the environment. Important characteristic of the POP load of the body is the TDI (tolerable daily intake) value for the human intake of pesticides, which is at Σ DDT 10 $\mu\text{g}/\text{body kg}$ [2].

Another unwanted feature of DDT and its metabolites are their bioaccumulation features [7]. Bioaccumulation meaning, the lipophilic DDT and its metabolites depositing in adipose tissues and they can hardly be mobilized. On the other hand, they can easily be mobilized by expression of breast milk, because the milking metabolism being different from normal excretion [7, 8, 16, 17]. Students can learn that the toxic compounds can become enriched in different tissues and mobilize in different ways. The biomagnification accelerates the issue, because the levels of pollutions multiply even several million times along the food chain [7, 13]. The long range transport and biomagnification of DDT and its metabolites cause high level pollution in living creatures on the top of food web (human and polar bears) in the Arctic Area, where the DDT was never applied [14]. These facts demonstrate, how pollution can appear in unexpected places even in high concentrations. Several publications dealt with the increased amounts of DDT in human breast milk. The DDT levels increase with the age of mothers [11, 17, 18], body mass index [11, 21] fat reach eating habits [7, 8, 18]. The concentration levels of DDT and metabolites are higher in the milk of primiparae mothers in cases of high pollution levels [7, 19, 20].

On the other hand, no significant differences were found between DDT levels of breast milk of primiparae and multiparae mothers, in the cases of the low pollution levels [8, 16, 17]. Recently, the lactated babies get several times lower amount of DDT and its metabolites than the TDI in Europe [17], but the pollution level of them exceed TDI in those territories, where DDT is used against malaria [16, 21].

These facts show obviously to the students that a compound with very useful effects can cause several unwanted side effects too. The previously mentioned unwanted effects of DDT and its metabolites resulted in the ban of the use of DDT for agricultural use in the vast majority of countries. It is worthy to note that Hungary was the first country, which withdrew DDT from agricultural use in 1966.

The highly contaminated areas of malaria, however, allow the recent use the DDT against malaria mosquito, mostly as indoor spraying [3, 4, 5, 9, 16]. This limited use of DDT seems to be a good compromise. The global warming results in an estimated threat of malaria cases [22], which keeps the DDT monitoring active, even in Europe.

The persistency, bioaccumulation and biomagnification features of DDT and its metabolites can cause even hundred million higher concentrations of these compounds in the human breast milk than their background level [7, 8, 16, 17]. The situation has become worse, because the newborn infants are in rather sensitive period of their life for endocrine disruptive compounds. These are the reasons why national and international campaigns were launched for the tests of DDT and its metabolites content of mother milk [20]. The well-established analysis methodology of DDT also helped the success of this campaign.

The low concentration levels of DDT and metabolites and the difficult matrix require multistep sample pretreatment and dedicated instrumental analysis [23, 24]. The WHO protocol does not favor any sample pretreatment and instrumental method, it allows for use of well-trained method of the analyzing laboratory [20]. Such examples help to build up an environmental approach, because the students can be personally involved.

Several methods were developed, but we choose the efficient SPE methods, because they are selective and they are good to concentrate the trace components. Recently the universal QuEChERS (Quick, Easy, Cheap, Effective, Rugged, Safe) methods have become more and more popular [25, 26]. These multiresidue methods are rather fast, easily managed, and require low solvent consumptions. These methods are based on acetonitrile extraction, and centrifugation followed by dispersive solid-phase extraction. The method was invented for analysis of vegetables and fruits. The modified QuEChERS method, however, can be applied for samples with high lipid content too [27, 28]. In these cases additional fat removing steps are advised. On the other hand, the QuEChERS method has not yet been applied frequently for breast milk samples. We decided to compare the QuEChERS method with the traditional cleaning method. An important task of higher education is to teach the recent best available techniques (BAT), such as the QuEChERS method.

GC/ECD or GC/MS methods are appropriate for instrumental analysis of DDT and its metabolite content of breast milk samples [23, 24, 26]. Dual - column analysis methods confirm the compounds' identification in the samples. The

parallel joint columns produce two retention times, and the same peak areas for one compound, which make the sample identification certain. This dedicated instrumentation shows the requirements of trace analysis.

Our aims with this report were the following:

- To show the recent presence of DDT and its metabolites in breast milk samples in Hungary, for the environmental engineering BSc students. This project is also good to involve the students in the scientific research of our institute.
- To see the tendency of concentration of the DDT and its metabolites in time scale and other parameters. In this way the student can learn the main tendencies of the POP pollutions.
- To prove the applicability of the QuEChERS method for breast milk samples showing a method of future.
- To give ability of manual work for students, in this way they can get experiences, which may be of use in their future jobs.
- To show that DDT is not an outdated analysis task even in Hungary. The possible threat of malaria keeps DDT analyses alive, even in Europe. Moreover, the bleed of illegal hidden depots can cause recent DDT pollutions too.

2 Experimental

2.1 Chemicals

Residue grade solvents (acetonitrile, dichloromethane, hexane, acetone) and anhydrous Na_2SO_4 were purchased from Sigma Aldrich. The used QuEChERS extraction kits (P/ 5982-5650) containing salt mixtures (4 g MgSO_4 ; 1 g NaCl ; 1 g NaCitrate ; 0.5 g disodium citrate sesquihydrate) The QuEChERS dispersive kit for SPE (P/N 5982-0028 2, Agilent) includes Eppendorf tube filled with 50 mg PSA, 50 mg C_{18} , 7.5 mg GCB, 150 mg MgSO_4 . Following standards were applied: Organochlorine Pesticide mixture from the Restek (Cat. no. 32415), and PCB 209 from the Riedel-de H  en (Cat No. 35587).

2.2 Instrumentation

The cooled (-10°C) and room temperature centrifugations were done in a laboratory centrifuge (Hermle) at 3000 rpm.

An Agilent Technologies 6890N Network GC System with HP7683 autosampler was used for dual μ GC/ECD analysis. Column pair was mounted in a press-fit Y-shaped glass 3-way union splitter. Parallel columns arrangement was used to overcome the coelution and identification difficulties. Two Restek produced columns were the following:

- Column A is Stx-CLPesticides (30 m x 0.25 mm x 0.20 μ m, Cat No. 11543).
- Column B is Stx-CLPesticides2 (30 m x 0.25 mm x 0.20 μ m, Cat. No. 11443). Parallel columns arrangement was used to overcome the coelution and identification difficulties.

2.3 Procedures

2.3.1 Collection of Breast Milk Samples (Sampling and Sample Preparation of Breast Milk Samples)

The tested persons were students and young teachers. In this way the students have personal contact with samples, because they know the donors. 8 breast milk samples were collected. The ages of mothers varied between 20-32 years. The mothers had their first delivery in seven cases, because it is expected that the DDT and its metabolite have the highest content in the case of first delivery [7, 20]. The samples were collected in the 3-10 weeks after they gave birth. The milk samples were stored in deep freezer until the extractions. The students came to know the basic rules of sampling and sample storages.

The frozen samples were let to thaw and then the liquids were homogenized. Method 1 required 25-50 g of milk portions using the EN 1528 method [23]. Method 2 used 10 g of samples for the QuEChERS method [26]. 1 μ g PCB 209 surrogate standard solutions were added to every sample. The use of surrogate standards show, how one can eliminate the effect of sample loss during the sample treatments.

The reference sample was 25 ml commercialized cow milk which was spiked at 10 μ g/kg level with the organochlorine pesticide mixture containing the DDT and its metabolites. This step drew the attention of students to the necessity of reference samples to eliminate the matrix effects.

2.3.2 Method 1: Sample Processing using Cooled Centrifugation (EN 1528-2:1998 (Point 6.1.4 Extraction by Cooled Centrifugation) [23])

The samples were centrifuged for 10 minutes at 2500 rpm at 5 °C. The solid fat phases were decanted and dissolved in 30 ml hexane and finally dried with anhydrous Na_2SO_4 . The hexane was evaporated and the weights of the remaining fats were measured.

0.5 grams of fats were molten on hot water baths, and mixed with 3 ml extraction solutions (ACN/CH₂Cl₂- 3:1) and centrifuged (3000 rpm) for 20 min. at -10 °C. The upper layers were decanted and collected in test tubes. The extractions of fats were repeated and the two extracts were unified. The organic phases were evaporated under gentle stream of N₂ and the final volumes were adjusted with hexane to 1 ml. These solutions were taken into GC vials and analyzed by GC-dual ECD.

2.3.3 Method 2: Sample Processing with the QuEChERS Method (EN 15662:2009) [26]

10 ml of acetonitrile were added to homogenized 10 ml liquid milk samples. 6.5 g of salt mixtures were poured into the tubes and vigorously shaken with vortex for 2 min. These were followed by centrifugation (4000-4500 rpm) for 15 min. The solutions were decanted into test tubes and kept in deep freezer overnight in order to remove the major part of the fat.

1 ml of “fat-free” acetonitrile solution was further cleaned-up by the QuEChERS dispersive kit (2 ml Eppendorf tube contains 50 mg PSA, 50 mg C₁₈, 7.5 mg GCB, 150 mg MgSO₄). These materials were homogenized with 1-2 min intensive shaking. Finally the solutions were centrifuged with 4000-4500 rpm for 2 minutes. An aliquot was taken out and evaporated to dryness at 35 °C using a gentle stream of nitrogen. Then it was dissolved in 1 ml hexane and taken into GC vials and analyzed by GC-dual ECD.

2.4 Analysis with GC-ECD Instrument

The GC measurements had the following temperature program: 90 °C (1.6 min), 50 °C/min 170 °C, 3.5 °C/min 300 °C. The injection modes were splitless 1 µl (1 min) at 270 °C. H₂ was the carrier gas with 13.01 psi inlet pressure. Detectors were µECDs at 330 °C using N₂ make-up gas.

The chromatograms were treated with ChemStation software (Agilent). Calibration curves are built/drawn in 0.2 -50 µg/l concentration range of DDE.

3 Results and Discussions

The chromatograms were appropriate to determine the compound of interests (Figure 2).

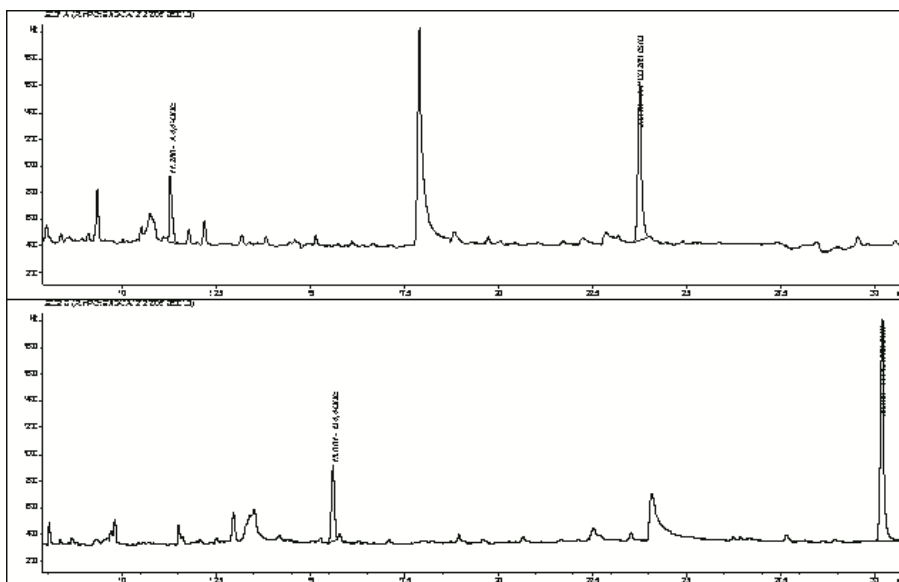


Figure 2

A typical GC/ECD dual channel chromatogram of a breast milk sample (HE) using cooled centrifugation sample processing method. Conditions: Column A: Stx-CLPesticides from the Restek (30 m x 0.25 mm x 0.20 μ m, Cat No. 11543) and Column B: Stx-CLPesticides2 from the Restek (30 m x 0.25 mm x 0.20 μ m, Cat. No. 11443) temperature program, 90 $^{\circ}$ C (1.6 min), 50 $^{\circ}$ C/min 170 $^{\circ}$ C, 3.5 $^{\circ}$ C/min 300 $^{\circ}$ C; injection mode, splitless 1 μ l (1 min) at 270 $^{\circ}$ C; carrier H_2 (13.01 psi); detector ECDs at 330 $^{\circ}$ C with N_2 make-up gas. Retention times are 11.286 min for 4,4'-DDE and 23.749 min for PCB 209 ISTD on Column A, and 15.601 min for 4,4'-DDE and 30.199 min for PCB 209 ISTD

The DDT, DDE and PCB 209 peaks were in disturbance free region of both chromatograms as results of effective sample cleaning and the use of very pure chemicals. The attention of students were drawn the importance of residue grade solvent, which is important for trace analysis, which becomes more emphasized when electron capture detector is used.

DDT was not detectable in any cases. The high ratio between DDE and DDT (DDT/DDE) shows old pollutions [2, 8]. It is interesting to note, that every mother was born after DDT had been banned in Hungary. Based on these examples, it is obvious, that the pollutions of DDT and its metabolites do not disappear during one cycle, but pollute several cycles along the food chain. The remaining DDE is a very demonstrative example for the persistency of chlorinated hydrocarbon pesticides. The presence of DDE without any detectable amount of DDT highlights the fact, that it is not enough to look for the compound applied, but the analysis of its metabolites is also important.

Therefore the calibration curve was constructed only for DDE. The calibration curve shows excellent 0.99908 correlations in 0.2 -50 μ g/l concentration range of

DDE according to Figure 3. The channel B shows 0.99725 correlations in the same range.

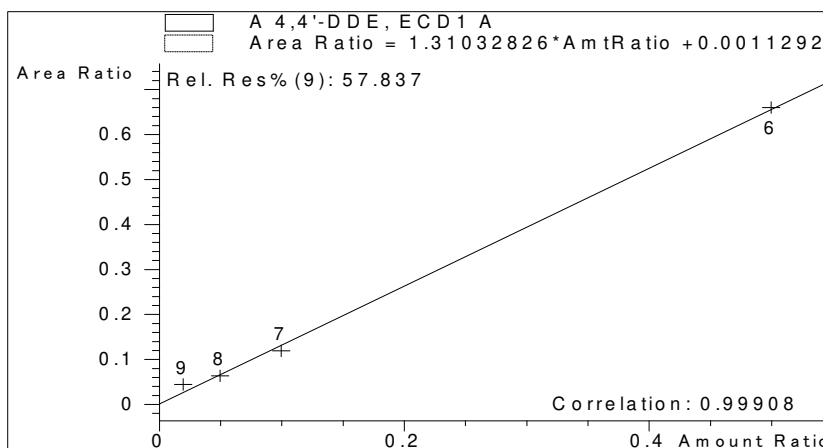


Figure 3

Calibration curve of DDE between 0.2-50 $\mu\text{g/l}$ concentration range using 100 $\mu\text{g/l}$ PCB 209. Column is Stx-CLPesticides2 from the Restek (30 m x 0.25 mm x 0.20 μm) at Chanel B.

DDE was quantified in 9 samples of 10 tested milk samples (Table 1). The milk sample of one mother (JK) was divided two part to check the reproducibility of method One of the mothers (VS) is a vegetarian, whose breast milk had not contained measurable DDE. Her data were omitted from further study. On the other hand the milk sample of VS was a good example, for the correlation between the eating habits of mothers and POP contaminants of their milk.

The mean values are 102 $\mu\text{g/kg}$ DDE in milk fat and 2.71 $\mu\text{g/l}$ in the tested breast milk samples using cooled centrifugation sample treatment methods. This value is significantly lower than was measured in WHO surveys (2006, 2002 1997) in Hungary.

The data of Table 1 are not enough for exact statistical evaluation; however, the students may observe the typical tendencies.

The extraction procedures are satisfactory, and the found 6.07 $\mu\text{g/kg}$ result show 117% recovery for reference sample (spiked at 5 ppb level). The reproducibility seems good, because the sub-samples of one mother (JKI, JKII) gave rather same results 2.43 $\mu\text{g/l}$ and 2.41 $\mu\text{g/l}$ concentration of DDE.

The modified QuEChERS method is also appropriate to establish the DDE content of breast milk (Fig. 4). The QuEChERS method is a universal sample pretreatment method, therefore its recovery can smaller for certain compounds than the special sample pretreatments methods for their targets compounds. This effect is well illustrated by the results of MJ and MJQ samples.

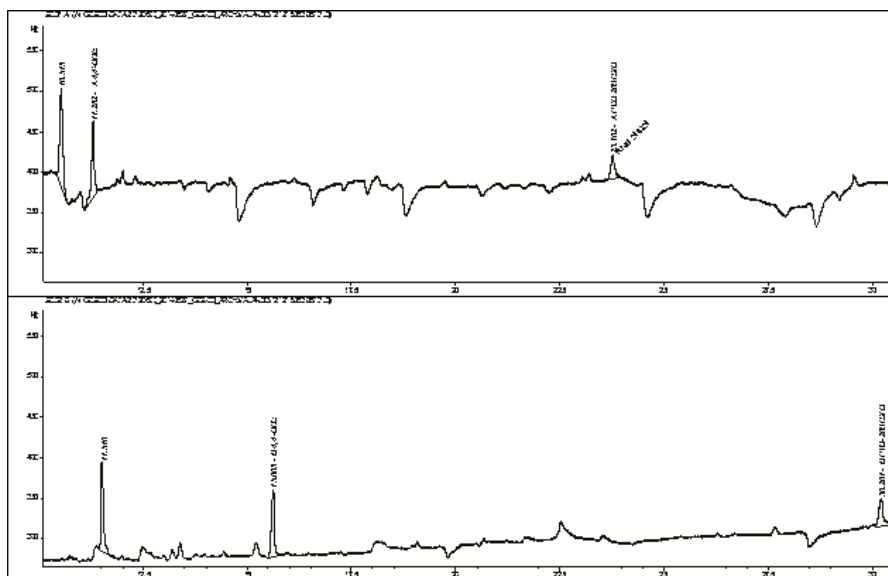


Figure 4

GC/ECD dual channel chromatogram of a breast milk sample (MEQ) using QuEChERS sample processing method. Conditions: Column A: Stx-CLPesticides from the Restek (30 m x 0.25 mm x 0.20 μ m, Cat No. 11543) and Column B: Stx-CLPesticides2 from the Restek (30 m x 0.25 mm x 0.20 μ m, Cat. No. 11443) temperature program, 90 $^{\circ}$ C (1.6 min), 50 $^{\circ}$ C/min 170 $^{\circ}$ C, 3.5 $^{\circ}$ C/min 300 $^{\circ}$ C; injection mode, splitless 1 μ l (1 min) at 270 $^{\circ}$ C; carrier H_2 (13.01 psi); detector ECDs at 330 $^{\circ}$ C with N_2 make-up gas. Retention times are 11.282 min for 4,4'-DDE and 23.762 min for PCB 209 ISTD on Column A, and 15.605 min for 4,4'-DDE and 30.207 min for PCB 209 ISTD.

The cooled centrifugation gave 4.72 μ g/l, and QuEChERS resulted in 4.04 μ g/l DDE content in the case of HE mother. The MJ mother showed 1.66 μ g/l with cooled centrifugation and 2.12 μ g/l with QuEChERS method for her breast milk.

Table 1
DDE contents of the breast milk of the tested mothers

Sample I.D.	Age of mother	Weight of mother***	Volume of the milk	Fat content of the milk	DDE conc. of the milk fat	DDE conc. of milk
Unit	year	kg	ml	G	μ g/l	μ g/l
Reference*	/	/	25	0.627	169.8	4.26
VG	29	73	25	0.944	41.6	1.57
MJ	30	72	50	1.86	83.15	1.66
MJ/Q**	30	72	10	/	/	2.12
JK/I	32	62	25	0.872	69.0	2.41
JK/II	32	62	25	0.893	68.2	2.43

FV	33	70	25	0.627	43.0	1.08
HE	34	72	50	3.9	236.0	4.72
HE/Q**	34	72	10	/	/	4.04
VS	35	62	25	0.885	< 20	< 0.5
KD	36	61	25	1.004	90.5	4.26

*spiked cow milk

**analyzed with QuEChERS method

*** weight of the mothers before their pregnancy

There are loose correlations ($r^2 = 0.7995$) between the fat content of breast milk samples and their DDE content.

The HE mother had the highest fat content in her milk (7.8%) and her milk showed highest (4.72 $\mu\text{g/L}$) DDE content from the non-vegetarian mothers. The milk sample of FV produced the lowest fat content (0.627%) and her milk contained lowest, only 1.08 $\mu\text{g/L}$ DDE content. This data shows that the eating habit influenced the DDE content of milk sample. Lipophilic character of DDE could also conclude from correlation of the fat content of breast milk and their DDE content.

No correlation (r^2 : 0.0169) was observed between the weight of mothers and DDE content of their milk. Perhaps their body mass index may correlate to the DDE contents of their milk.

The ages of mothers and DDE content of milk fat also show a weak correlation (r^2 : 0.4425). This effect can explain the bioaccumulation feature of then DDE. The KD sample, a mother aged 36 had second highest DDE content (4.26 $\mu\text{g/L}$) in her milk. The VG, the youngest at 29, had second lowest DDE content (1.57 $\mu\text{g/L}$) in her milk.

The data of Table 1 also presents, that the samples from biological origin could produce a big deviation (s: 1.31). The highest DDE content was almost four times higher than the lowest content.

Conclusion

These experiments and results of this paper served as an excellent tool for the education of POP in the environmental engineering courses. The relatively low sample numbers do not allow for exact statistical evaluation, but the main tendency has been manifested. No recent DDT pollution was recognized in the breast milk samples. On the other hand, the overwhelming part of the breast milk samples of Hungarian mothers contain DDE even today, showing the high persistency feature of DDT and its metabolites. All of the samples contained less DDE than tolerable daily intake. The DDT and its metabolites have not disappeared after one cycle from the food chain, but they remain for several cycles. This establishment was supported by the fact that the tested mothers were born after the ban of DDT in Hungary. Eating habits may influence the DDE content of breast milk, because all of the samples contained DDE except the milk

of a vegetarian woman. The used sample preparation methods were appropriate to establish the DDE contents of the sample. The results of modified QuEChERS method are comparable with the results of traditional cold centrifugation method. Loose correlations were found between the age, fat content of milk samples and their DDE content.

These results demonstrate the requirements of developed instrumental background and laborious sample treatments for environmental trace analysis. The established correlations show the features of POP in biological matrices. The analysis of DDT and its metabolite cannot be omitted from the education of environmental engineers; in spite of agrochemical use of DDT was having been banned for decades. Since global warming carries a possible risk for spreading of malaria, DDT analyses remain active task for environmental protection.

The established results demonstrate the following:

- The analysis of DDT and its metabolite is good example for the persistency bioaccumulation and biomagnifications of POP compounds.
- The measurements thought the appropriate sampling, sample storage, sample pretreatments, and instrumental measurements.
- These tests brought personal involvements for the students to build up their environmental attitudes.

Acknowledgment

The financial support of OTKA grant K72861 is acknowledged.

References

- [1] D. Wei, T. Kameya, K. Urano: Environmental Management of Pesticidal POPs in China: Past, Present and Future, *Environment International*, 33 (2007) 894
- [2] T. Lotz T. (Eds.): National Implementation Plan of The Stockholm Convention for The Reduction of Persistent Organic Pollutants in The Environment, Project GF/HUN/01/005 UNIDO on Enabling Activities to Facilitate Early Action on the Implementation of the Stockholm Convention on Persistent Organic Pollutants (POPs) in Hungary (2005)
- [3] United Nations Stockholm Convention on Persistent Organic Pollutants list (2001) <http://chm.pops.int/Convention/tabid/54/Default.aspx>
- [4] B. Eskenazi, J. Chevrier, L. Goldman Rosas, H. A. Anderson, M. S. Bornman, H. Bouwman, A. Chen, B. A. Cohn, C. de Jager, D. S. Henshel, F. Leipzig, J. S. Leipzig, E. C. Lorenz, S. M. Snedeker, and D. Stapleton: The Pine River Statement: Human Health Consequences of DDT Use, *Environmental Health Perspectives* 117 (2009) 1359

- [5] H. Bouwman, H. van den Berg, and H. Kylin: DDT and Malaria Prevention: Addressing the Paradox, *Environmental Health Perspectives* 119 (2011) 744
- [6] M. Ricking, J. Schwarzbauer: DDT Isomers and Metabolites in the Environment: an Overview, *Environ Chem Lett* 10 (2012) 317
- [7] R. Y. Wang, L. L. Needham: Environmental Chemicals: from the Environment to Food, to Breast Milk, to the Infant. *Journal of Toxicology and Environmental Health, Part B* 10 (2007) 597
- [8] O. Mikes, P. Cupr, L. Kohút, A. Krsková, M. Cerná: Fifteen Years of Monitoring of POPs in the breast milk, Czech Republic, 1994-2009 *Environ Sci Pollut Res* 19 (2012) 1936
- [9] C. E. Lundholm: DDE-Induced Eggshell Thinning in Birds, *Comp Biochem Physiol C Pharmacol Toxicol Endocrinol* 118 (1997) 113
- [10] T. F. Bidleman, L. M. Jantunen, P. B. Kurt-Karakus, F. Wong: Chiral Persistent Organic Pollutants as Tracers of Atmospheric Sources and Fate: Review and Prospects for Investigating Climate Change Influences, *Atmospheric Pollution Research* 3(2012) 371
- [11] ATSDR, Agency for Toxic Substances and Disease Registry, Public Health Service, U.S. Department of Health and Human Services) Toxicological profile for DDT, DDE and DDD (2002) [http:// www.atsdr.cdc.gov/toxprofiles/tp35.pdf](http://www.atsdr.cdc.gov/toxprofiles/tp35.pdf)
- [12] R. Carson: *Silent spring*. Houghton Mifflin, Boston (1962)
- [13] T. Colborn, D. Dumanoski, J. P. Myers: *Our Stolen Future: Are We Threatening Our Fertility, Intelligence, and Survival? A Scientific Detective Story*, Dutton (1996)
- [14] L. Holm, A. Blomqvist, I. Brandt, B. Brunström, Y. Ridderstrale, C. Berg Embryonic Exposure to *o,p'*-DDT Causes Eggshell Thinning and Altered Shell Gland Carbonic Anhydrase Expression in the Domestic Hen, *Environmental Toxicology and Chemistry* 25 (2006) 2787
- [15] D. M. Fry, C. K. Toone: DDT-induced Feminization of Gull Embryos *Science*. 213(1981) 922
- [16] Azeredo. J. P. M. Torres, M. de Freitas Fonseca, J. L. Britto, W. R. Bastos, C. E. A. Silva, G. Cavalcanti, R. O. Meire, P. N. Sarcinelli, L. Claudio, S. Markowitz, O. Malm: DDT and Its Metabolites in Breast Milk from the Madeira River Basin in the Amazon, Brazil, *Chemosphere* 73 (2008) 246
- [17] Guerranti, M. Palmieri, M. Mariottini, S. E. Focardi: Persistent Organic Pollutants in HumanMilk from Central Italy: Levels and Time Trends, *International Scholarly Research Network Toxicology* (2011) Article ID 107514

- [18] J. P. Arrebola, M. F. Fernández, N. Olea, R. Ramos, P. Martin-Olmedo: Human Exposure to p,p'-dichlorodiphenyldichloroethylene (p,p'-DDE) in Urban and Semi-Rural Areas in Southeast Spain: A Gender Perspective, *Science of the Total Environment* 458-460 (2013) 209
- [19] H. Bouwman, H. Kylin, B. Sereda, R. Bornman: High Levels of DDT in Breast Milk: Intake, Risk, Lactation Duration, and Involvement of Gender, *Environmental Pollution* 170 (2012) 63
- [20] Fourth WHO-Coordinated Survey of Human Milk for Persistent Organic Pollutants in Cooperation with UNEP Guidelines for Developing a National Protocol (2007) <http://www.who.int/foodsafety/chem/POPprotocol.pdf>
- [21] Torres-Dosal, &R. I. Martinez-Salinas, D. Hernandez-Benavides, F. J. Perez-Vazquez, C. Ilizaliturri-Hernandez, I. N. Perez-Maldonado: Assessment of the Levels of DDT and DDE in Soil and Blood Samples from Tabasco, Mexico *Environ Monit Assess* 184 (2012) 7551
- [22] D. J. Rogers, S. E Randolph: The Global Spread of Malaria in a Future, Warmer World, *Science* 289 (2000) 1763
- [23] Fatty food. Determination of Pesticides and Polychlorinated Biphenyls (PCBs), EN 1528-1-4:1998
- [24] Organochlorine Pesticides by Gas Chromatography, EPA- Method-8081B, 2000, <http://www.caslab.com/EPA-Methods/PDF/EPA-Method-8081B.pdf>
- [25] M. Anastassiades, S. J. Lehotay, D. Stajnbaher, F. J. Schenck: Fast and Easy Multiresidue Method Employing Acetonitrile Extraction/Partitioning and "Dispersive Solid-Phase Extraction" for the Determination of Pesticide Residues in Produce, *J. AOAC Int.* 86 (2003) 412
- [26] Foods of plant origin - Determination of Pesticide Residues using GC-MS and/or LC-MS/MS Following Acetonitrile Extraction/Partitioning and Clean-up by Dispersive SPE - QuEChERS-method, EN 15662:2009
- [27] V. Samanidou, S. Nisyrliou: Multi-Residue Methods for Confirmatory Determination of Antibiotics in Milk. *Journal of Separation Science*, 31 (2008) 2068
- [28] M. J. Misselwitz, J. Kowalski, J. J Cochran: The QuEChERS Extraction Approach and Comprehensive Two – Dimensional. Gas Chromatography of Halogenated Persistent Organic Pollutants in Cow Milk and Human Milk 2012, www.restek.com/pdfs/pcon2012_155-7_poll-in-milk.pdf

2015 Reviewers

Abaffy, József
Ancza, Erzsébet
Benedek, András
Betlejewska, Stasiak
Borbély, Ákos
Csink, László
Csobán, Attila
Csoka, Levente
Dörfler, Viktor
Drexler, Dániel András
Eigner, György
Eleőd, András
Elmenreich, Wilfried
Farkas, András
Fekete, Zsolt
Ferenci, Tamás
Fullér, Róbert
Füstös, János
Goda, Tibor
Haidegger, Tamás
Harmati, István
Horváth, Miklós
Johanyák, Zsolt Csaba
Kádár, Péter
Keszthelyi, András
Kiss, Rita
Klespitz, József
Kokas-Palicska, Livia
Kósa, Balázs
Kovács, Levente
Kozlovsky, Miklós

Krómer, István
Lazányi, Kornélia
Mikó, Balázs
Milosavljevic, Cedimir
Mura, Ladislav
Nagy, Péter Tibor
Nagy, Tibor István
Nagy, Viktor
Pálfi, Judith
Par, Kerem
Pavlović, Živko
Pethes, Róbert
Poós, Tibor
Porkoláb, Zoltán
Póser, Valéria
Rakovics, Vilmos
Ređep, Nina Begičević
Réti Tamás
Ruszinkó, Endre
Szabó, Ferenc
Szénási, Sándor
Szentgyörgyvölgyi, Rozália
Takács, Árpád
Takács, Márta
Tar, József
Tiba, Zsolt
Tick, József
Tóth, Zoltán
Váradi, Károly
Velencei, Jolán
Windisch, Gergely