An Approximate Analytic Solution of the Inventory Balance Delay Differential Equation

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Abstract: In this paper we present an analytic investigation of the continuous time representation of the inventory balance equation supplemented by an order-up-to replenishment policy. The adopted model parameters describe the startup of a distribution facility facing a constant demand. The exact solution is approximated by a complex exponential function containing integration constants that are dependent on the principal mode of the Lambert W function. We give a detailed review of the solution strategy emphasising some underexposed components, and provide a fair discussion of its limitations. In particular we give a detailed study on the matching of the exact and the approximate analytic solution. We also derive and analyse damped non-oscillatory solutions that have been neglected in the literature. Although the model is prone to the well known permanent inventory deficit, it serves as a solid foundation for future improvements.

Keywords: inventory control, ordering policy, stability, Lambert function.

1. Introduction

"One of the principal reasons used to justify investments in inventories is its role as a buffer to absorb demand variability"; state Baganha and Cohen in 1998 [2]. More than a decade later we find, that modern supply chains composed of distribution units with safety stock are often prone to the instability of orders amplifying upwards in the chain, known as the bullwhip effect. Dejonckheere *et al.* [7] resolve this conundrum by claiming that

"...inventories can have a stabilizing effect on demand variation provided the replenishment decision is designed carefully via common control theory techniques." Careful design translates to the construction and the analysis of the inventory's mathematical model, serving as the basis of the implemented replenishment policy.

There are different models available in the literature to describe an inventory. The basic concepts of the method exploiting the advances in the field of control theory were laid by Simon [13], Vassian [15], Deizel and Elion [8]. More recently the control theoretic approach was used as a powerful tool in the field of inventory management by John *et al.* [11], Berry *et al.* [3], Disney *et al.* [9], Towill *et al.* [14] and others. The basic philosophy behind the method is threefold. First, the Laplace-transform is applied on the equations governing the dynamics of the inventory, *i.e.* the problem formulated in the time domain is transformed into the operator domain. Second, the transfer function of the system relating the transformed demand and order at a given distribution unit is derived. Third, the tools provided by control theory are exploited, such as stability-, frequency response- and spectral analysis.

A conceptually different line of research is based on stochastic views. The popular paper of Lee *et al.* [12] revealed five causes of the bullwhip effect induced by rational decision making policies, while Chen *et al.* [4] investigated the effect of demand signal processing. The methodology gives insights into the probabilistic nature of inventory control.

The third important family of models is based on the continuous time representation. The dynamics of the system is governed by ordinary differential equations (ODE) describing the balance of the inventory. In this framework all operations are performed in the time domain. Forrester [10] had a widely recognized pioneering contribution to the investigation of order amplification caused by non-zero lead time and demand signal processing. He also derived a second-order ordinary differential equation with a special term approximating the effect of lead time. Another path followed by Warburton [16] leads to the field of delay differential equations (DDE), requiring more elaborate solution strategies. The difficulty lies in the fact that the resulting characteristic equation is transcendent, with an infinite number of roots. Asl *et al.* [1] proposed a solution strategy by exploiting the advances in the theory of the Lambert W function due to Corless *et al.* [6]. The basic idea is that the solution of the inventory balance equation is assumed in the form of complex exponentials, and the integration constants are obtained in terms of the Lambert W function. Warburton [16] applied these ideas to present approximate analytic solutions for the inventory balance equation. He also explored the response of this continuous model to a variety of demand patterns. In [16] the basis of the approximate exponential formalism are laid and the startup of a new distribution facility facing a constant demand is modelled. The response of the inventory to a step function, a ramp and an impulse function is studied in [17–19], respectively.

This brief summary demonstrates, that the Lambert W function based exponential approximation has become a popular tool for the investigation of different replenishment policies applied to a variety of demand patterns in the continuous framework. The main reasons are:

- the tractability of the analysis,
- easy to determine stability properties,
- clear dependence on model parameters,
- a number of convincing test cases.

However, a careful study of the model equations justifies, that subtle, yet important components of the technique are not formulated by adequate precision in the literature. Thus, the aim of this paper fourfold. First, we present the complete description of the solution strategy emphasising certain underexposed components. This part of the paper also serves for future reference. Second, we dive into the details of one particular part of the solution strategy, *i.e.* the determination of certain integration constants. A part of the published theory is valid only in special cases, while other parts are in error. We give the derivation of the proper formulae and support the study with the presentation of test cases. The third aim is to demonstrate the limitations of the approach. In [16] the author claims, that the exponential approximation performs well for the whole range of parameters. We present test cases contradicting to this statement. The fourth aim is to give a detailed analysis of non-oscillatory exponential decaying solutions, that are not investigated in the related works [16–19].

In the following paragraphs we revisit the basic problem of continuous inventory control. The focus is on the pioneering paper of Warburton [16] that describes the foundations of the exponential approximation strategy applied to the startup of a distribution facility. For simplicity, WIP terms and demand smoothing are omitted just like in [16]. The structure of this paper is the following. In section 2 we introduce the labelling conventions and formulate the differential equation governing the dynamics of the inventory. In section 3 the exact analytic solution for vanishing lead time is described. The exponential approximation for non-zero lead time is analysed in section 4. Supporting test cases are presented in section 5. The implications of the analytic derivations are discussed in section 6 while some concluding remarks are given in the last section.

2. The inventory balance equation

We consider the problem of linear inventory control. The objective is to continuously satisfy the observed demand while maintaining an inventory to guard against the stochastic nature of real life processes. The demand rate of $D(t)$ items per time unit is completely fulfilled if possible. Unfulfilled demands are backlogged. The aim of the adopted inventory replenishment policy is to drive the actual inventory level $I(t)$ towards its desired target value $\tilde{I}$. At time $t = 0$ the inventory is at $I(0) = I_0$. In the works of Warburton [17–19] it is assumed that

$$I_0 = \tilde{I}. \tag{1}$$

Here we release this assumption and study the more general case by letting the initial and the target inventory levels to be different. In order to manage the inventory, orders are placed with a rate of $O(t)$, and as an effect, items are received at the rate of $R(t)$. The temporal variation of $I(t)$ is governed by the inventory balance equation

$$\frac{dI}{dt} = R(t) - D(t). \tag{2}$$

It is assumed, that the lead time τ is a non-negative constant number, *i.e.* the receiving rate follows the delayed order rate according to

$$R(t) = O(t - \tau). \tag{3}$$

Inserting the last equation into (2), we obtain another from of the inventory balance equation, clearly reflecting its special delay character

$$\frac{dI}{dt} = O(t - \tau) - D(t). \tag{4}$$

The dynamic response of the inventory to the observed demand is characterized by the adopted inventory replenishment policy. In this paper we employ a fractional order-up-to policy that is a simplified variant of the *automatic pipeline, inventory and order-based production control system* (APIOBPCS) of John *et al.* [11]

$$O(t) = \frac{\tilde{I} - I(t)}{T}, \tag{5}$$

where T is a relaxation factor, also known as a controller, adjusting the responsiveness of the policy. The higher the value of T, the slower the response of the policy is. The system is closed by the demand rate that is chosen to be a step function through this paper

$$D(t) = D_0 \quad \text{for} \quad t < 0 \quad \text{and} \quad D(t) = D_1 = D_0 + \widehat{D} \quad \text{for} \quad t \geq 0, \tag{6}$$

where $\widehat{D} = D_1 - D_0$ is the jump in the demand.

2.1. Initial conditions

In the case of $\tau = 0$ the inventory balance equation (4) becomes a simple first-order ODE that is subject to an initial condition at $t = 0$

$$I(0) = I_0. \tag{7}$$

However, the choice of $\tau > 0$ changes the entire character of the problem, since now we deal with a DDE and the initial condition turns to be a functional equation [1]. The standard procedure to treat this setup is as follows. For $t < 0$ we assume that the inventory is in equilibrium with $R(t) = D(t) = O(t) = D_0$ and $I(t) = I_0$. At $t = 0$ the demand changes, and the solution is readily calculated for $0 \leq t \leq \tau$. By following established nomenclature [1], interval $0 \leq t \leq \tau$ is referred to as the *pre-interval*, while the corresponding exact solution $\phi(t)$ is called the *pre-shape function*. The functional initial condition for the inventory balance equation is

$$I(t) = \phi(t) \quad \text{if} \quad 0 \leq t \leq \tau. \tag{8}$$

Now the task is to find a particular solution of equation (4) that satisfies condition (8). As we discuss later in this paper, in practical applications the exact satisfaction of (8) is relaxed due to the mathematical difficulties characterizing DDEs.

In this paper we investigate the initial setting considered by Warburton [16], where the following conditions are adopted:

$$D_0 = 0 \quad \text{for} \quad t < 0, \quad I(0) = I_0 \quad \text{and} \quad D(t) = D_1 = \widehat{D} \quad \text{for} \quad t \geq 0, \tag{9}$$

describing the startup of a distribution facility facing a constant demand.

3. The exact solution for $\tau = 0$

In the case of vanishing lead time ($\tau = 0$) the inventory equation takes the following simple form

$$\frac{dI(t)}{dt} = \frac{\tilde{I} - I(t)}{T} - D_1. \tag{10}$$

The corresponding homogeneous equation

$$\frac{dI(t)}{dt} + \frac{I(t)}{T} = 0 \tag{11}$$

has a general solution as a simple exponential

$$I(t) = ce^{-\frac{t}{T}}. \tag{12}$$

The particular solution of inhomogeneous equation (10) satisfying initial condition (7) is:

$$I(t) = \left(I_0 - \tilde{I} + D_1 T\right) e^{-\frac{t}{T}} + \tilde{I} - D_1 T. \tag{13}$$

The corresponding order rate is

$$O(t) = D_1 - \left(\frac{I_0 - \tilde{I}}{T} + D_1\right) e^{-\frac{t}{T}}. \tag{14}$$

Equations (13) and (14) imply that for zero lead time the system is always stable, *i.e.* it exponentially relaxes to a steady state. The asymptotic behaviour of the inventory

$$\lim_{t \to \infty} I(t) = \tilde{I} - D_1 T \tag{15}$$

reflects the presence of the permanent inventory deficit with the magnitude of $D_1 T$. This feature is a well known deficiency of ordering policy (5) focusing only on the replenishment of the inventory. On the other hand, the order rate asymptotically approaches the demand rate

$$\lim_{t\to\infty} O(t) = D_1. \tag{16}$$

4. The approximate analytic solution for $0 < \tau$

In this section we present the approximate solution of the inventory balance equation in the form of complex exponentials. First we give a short introduction into the Lambert W function, since it plays a fundamental role in the solution of the emerging characteristic equation. Next, we calculate the pre-shape function, that is followed by the derivation of the particular approximate analytic solution. Since the description of the matching procedure between the preshape function and the approximation is not consistently covered in the literature, we give a detailed discussion of the subject.

4.1. The Lambert W function

The Lambert W function is defined by $W : \mathbb{C} \to \mathbb{C}$ satisfying equation

$$W(z)\, e^{W(z)} = z, \tag{17}$$

where z is a complex variable. An excellent overview of its history, applications, and related numerical analysis can be found in the work of Corless *et al.* [6]. It is highly relevant to our work that the Lambert W function is multivalued with an infinite number of branches. The m-th branch labelled by W_m satisfies equation (17) for all integer values of m. Amongst many fields of science it has its application in the solution of linear first-order delay differential equations [1], since the corresponding characteristic equation can be cast into form (17). In the field of linear inventory control the potential of the Lambert W function has been exploited by Warburton [16]. The 0-th branch (W_0) is referred to as the principal branch of the Lambert W function. Since it plays a fundamental role in our study, its basic properties are summarized below when its domain is reduced to $\mathbb{R}^-$. The real ($Re(W_0)$) and the imaginary ($Im(W_0)$) components of W_0 are plotted on figure 1. There are two significant values of $z \in \mathbb{R}^-$: $-\pi/2$ and $-1/e$. When $-\pi/2 < z < 0$, $Re(W_0)$ is negative. The zeros of $Re(W_0)$ are at $z = -\pi/2$ and $z = 0$. The minimum value of $Re(W_0)$ is taken at $z = -1/e$

$$\min_{z<0} Re(W_0(z)) = Re(W_0(-1/e)) = -1. \tag{18}$$

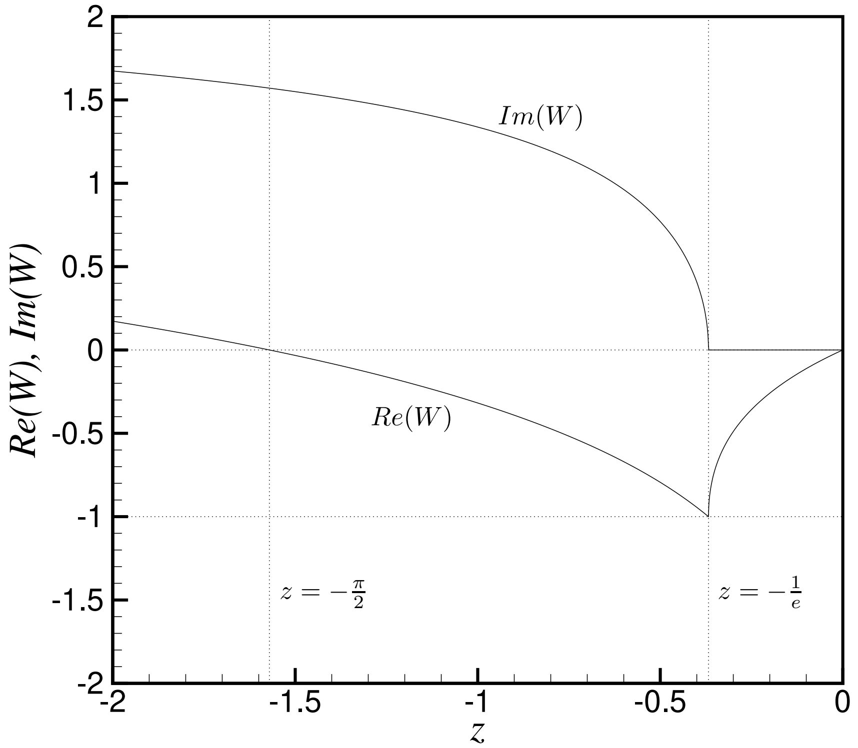

Figure 1: The real and the imaginary components of the principal branch of the Lambert W Function $W_0(z)$ in the case of purely real z. The important values of $z = -\pi/2$ and $z = -1/e$ are labelled by dotted lines.

When $z < -\pi/2$, $Re(W_0)$ is positive. For $-1/e \leq z \leq 0$ W_0 is purely real, *i.e.* $Im(W_0) = 0$. Finally, $Im(W_0)$ is positive for $z < -1/e$. This information will be exploited in the following paragraphs.

4.2. Computation of the pre-shape function

Condition (9) implies, that in the case of non-zero lead time no orders are delivered until $t = \tau$, thus, for $0 \leq t < \tau$ the receiving rate vanishes: $R(t) = D_0 = 0$. The corresponding form of the inventory equation is

$$\frac{dI(t)}{dt} = -\widehat{D}. \tag{19}$$

The solution matching initial condition (7) provides the pre-shape function as

$$\phi(t) = I_0 - \widehat{D}t, \tag{20}$$

while the corresponding order rate is:

$$O(t) = \frac{\tilde{I} - I_0}{T} + \frac{\widehat{D}}{T}t. \tag{21}$$

4.3. The approximate exponential solution for $\tau \leq t$

For $\tau \leq t$ the inventory equation becomes an inhomogeneous delay differential equation

$$\frac{dI(t)}{dt} = \frac{\tilde{I} - I(t-\tau)}{T} - D_1, \tag{22}$$

that can be solved by the method described in [1, 16]. First, the general solution to the homogeneous equation is obtained, next a particular solution to the inhomogeneous equation is calculated.

4.3.1 The homogeneous term

The homogeneous part of equation (22) is

$$\frac{dI(t)}{dt} + \frac{I(t-\tau)}{T} = 0. \tag{23}$$

Following the basic concepts of [1, 16], we look for the solution in the form of

$$I(t) = Ae^{qt}, \tag{24}$$

where A and q are constant complex numbers. The actual level of the inventory is considered to be the real part of (24). Substituting expansion (24) into equation (23) we arrive to

$$Ae^{qt}\left(q+\frac{e^{-q\tau}}{T}\right)=0. \tag{25}$$

The corresponding characteristics equation is

$$q+\frac{e^{-q\tau}}{T}=0. \tag{26}$$

By straightforward algebraic manipulations the above equation can be transformed into

$$q\tau\, e^{q\tau}=-\frac{\tau}{T}, \tag{27}$$

that is formally identical to equation (17) serving the basis for the introduction of the Lambert W function. Comparison of equations (27) and (17) immediately yields, that there are an infinite number of values exist for q. The m-th value of q labelled by q_m is associated with the m-th branch of the Lambert W Function

$$W_m(z)=q_m\tau \quad \text{and} \quad z=-\frac{\tau}{T}, \tag{28}$$

leading to

$$q_m=\frac{W_m(-\tau/T)}{\tau}. \tag{29}$$

The m-th *mode* of the solution of the inventory equation depending on the m-th branch is

$$I_m(t)=A_m e^{q_m t}, \tag{30}$$

where q_m represents known complex coefficients, while A_m labels the unknown complex integration constants depending on m. Due to the linearity of the inventory equation, any linear combination of the modes is a solution to (23)

$$I(t) = \sum_{m=-\infty}^{\infty} A_m e^{q_m t}. \quad (31)$$

4.3.2 The inhomogeneous term

Since the system is excited by a constant term, we look for a particular solution of the inhomogeneous equation (22) in the following form

$$I(t) = B, \quad (32)$$

where B is a constant coefficient. Substitution of expansion (32) into equation (22) yields

$$B = \tilde{I} - D_1 T. \quad (33)$$

4.3.3 The general solution

The general solution of equation (22) containing the yet unknown constant coefficients A_m is the sum of the general solution of the homogeneous equation and a particular solution of the inhomogeneous equation

$$I(t) = \tilde{I} - D_1 T + \sum_{m=-\infty}^{\infty} A_m e^{q_m t}. \quad (34)$$

The corresponding order rate is

$$O(t) = D_1 - \sum_{m=-\infty}^{\infty} \frac{A_m}{T} e^{q_m t}. \quad (35)$$

4.3.4 Notes on the exponential expansion

The particular solution of equation (22) corresponding to the investigated problem has to satisfy the related initial condition given by (8):

$$\tilde{I} - D_1 T + \sum_{m=-\infty}^{\infty} A_m e^{q_m t} = \phi(t) \quad \text{if} \quad 0 \le t \le \tau, \tag{36}$$

where, in principle, ϕ could be any *reasonable* functions. The last equation assumes, that any functions that are differentiable over $[0,\tau]$, except at a finite number of points, can be expanded as the infinite sum of complex exponentials, with the strong restriction, that the exponents are determined by the branches of the Lambert W function evaluated at $z = -\tau/T$ (see equation (29)). According to our best knowledge, such a proof does not exist. Nevertheless, in a practical calculation only a finite number of $2M + 1$ (usually symmetric) modes are taken into consideration, leading to the following approximate solution of the inventory equation (4) subject to condition (8)

$$I_M(t) = \tilde{I} - D_1 T + \sum_{m=-M}^{M} A_m e^{q_m t}. \tag{37}$$

The lack of sound analytic investigation of the convergence of expansion (36) has two implications. First, it is not clear how large the value of M should be in order to get an acceptable solution. Second, there is no unique method for the calculation of the corresponding A_m coefficients. Due to the delay nature of the problem, we not only have to match $I(t)$ at $t = 0$, but at all points within interval $[0,\tau]$. Clearly, in a general case an exact fit does not exist (*e.g.* consider a linear pre-shape function). Thus, approximate fitting mechanisms have to be applied, that are not unique.

There are three conceptually different principles can be found in the literature to approach the problem. Asl *et al.* [1] propose a method to fit approximation (37) at $2M + 1$ equidistant points over the pre-interval, and to obtain coefficients A_m from a set of linear algebraic equations, provided that the corresponding matrix is invertible. Warburton and Disney [19] argue that the matrix is badly conditioned and that a large number of modes (20-30) are needed to be taken into consideration to get near the pre-shape function. They choose to follow the idea of Corless [5] by minimizing the following integral

$$\int_0^\tau \left[\phi(t) - I_M(t)\right]^2 \, dt. \tag{38}$$

Unfortunately, the mathematical details of this minimization procedure are omitted in [19]. A careful examination of the presented material implies that the results should be treated with caution, warranting for further inspection. In this paper we do not aim the clarification of the issue.

The third option is to set $M = 0$ and approximate the exact solution $\mathcal{I}(t)$ of inventory equation (4) subject to condition (8) via $I_0(t)$, depending on the principal mode of the Lambert W function:

$$\mathcal{I}(t) \approx I_0(t). \tag{39}$$

In all related studies of Warburton [16–19] it is concluded, that this choice provides a sufficiently accurate representation of the inventory in practical applications. The author claims, that the highest deviation of $I_0(t)$ from the reference solution is less than 3% at the first peak. However, as we point out later, this statement does not accurately reflect reality.

In this paper our interest goes exclusively into the investigation of approximation (39). For the sake of simplicity, from this point on subscript 0 is omitted, and we adopt the following labelling conventions

$$W = W_0(-\tau/T), \quad A = A_0 \quad \text{and} \quad I(t) \equiv I_0(t) = \tilde{I} - D_1 T + A e^{\frac{W t}{\tau}}, \tag{40}$$

where τ and T are real constants, W is a known complex constant defined in terms of τ and T, and A is a complex integration constant specified below.

4.3.5 Computation of the integration constants

Let us start by studying the behaviour of the *exact* solution $\mathcal{I}(t)$ and its derivative at the left and at the right vicinities of $t = \tau$. The known pre-shape function (20) provides the left limit

$$I_L = \lim_{t\to\tau-} \phi(t) = \lim_{t\to\tau-} (I_0 - \widehat{D}t) = I_0 - \widehat{D}\tau, \tag{41}$$

$$\partial I_L = \lim_{t\to\tau-} \frac{d\phi(t)}{dt} = \lim_{t\to\tau-} \frac{d}{dt}(I_0 - \widehat{D}t) = -\widehat{D}. \tag{42}$$

Approximation (34) yields the right limit

$$I_R = \lim_{t\to\tau+} I(t) = \lim_{t\to\tau+} \left(\tilde{I} - D_1 T + Ae^{\frac{Wt}{\tau}}\right) = \tilde{I} - D_1 T + Ae^{W}, \tag{43}$$

$$\partial I_R = \lim_{t\to\tau+} \frac{dI(t)}{dt} = \lim_{t\to\tau+} \frac{d}{dt} \left(\tilde{I} - D_1 T + Ae^{\frac{Wt}{\tau}}\right) = \frac{AW}{\tau} e^{W}. \tag{44}$$

Note, that inventory equation (4) itself defines the known exact value of $d\mathcal{I}(t)/dt$ also at the left vicinity of τ (with $O(t) = 0$) and at the right vicinity of τ (with $O(t)$ computed by equation (5)):

$$\lim_{t\to\tau-} \frac{d\mathcal{I}(t)}{dt} = -\widehat{D}, \tag{45}$$

$$\lim_{t\to\tau+} \frac{d\mathcal{I}(t)}{dt} = \lim_{t\to\tau+} \left(\frac{\tilde{I} - I_0 + \widehat{D}(t-\tau)}{T} - D_1\right) = \frac{d\mathcal{I}(t)}{dt}|_{t=\tau} = \frac{\tilde{I} - I_0}{T} - D_1. \tag{46}$$

The last two equations imply that in general, the first-derivative of the exact solution is right continuous and left discontinuous at $t = \tau$. The slope is continuous at $t = \tau$ if equation (1) holds and $D_0 = 0$.

Now we are ready to formulate appropriate matching conditions. Recall, that we are looking for a single complex exponential function approximating the unknown solution of the inventory balance equation. In order to complete our derivations, we have yet to determine the value of the remaining integration constant A, that is a complex number. There are two scalar unknowns, so we can require the satisfaction of two independent scalar conditions at most. One option would be to minimize the following integral

$$\int_0^\tau \left[\phi(t) - Re(I(t))\right]^2 \, dt. \tag{47}$$

Here we follow another approach proposed by Warburton [16]. The basic principle is to ensure, that at $t = \tau$ the exponential approximation is launched from its proper level with the proper slope. In other words, we have to match approximation (34) and its first-derivative with their respective exact values.

First we focus on the computation of I_R that is obtained from the continuity of the inventory. In the time continuous framework it is natural to assume that the inventory is continuous at $t = \tau$, unless the demand is represented by an impulse function at that instance; a theoretically possible case that we do not cover. Thus, matching the inventory (43) to its exact value (41) yields

$$\tilde{I} - D_1 T + A\, e^{W} = I_0 - \widehat{D}\tau, \tag{48}$$

Next, the derivative of the exponential approximation (44) is matched with the exact value of the slope (46)

$$\frac{AW}{\tau}\, e^{W} = \frac{\tilde{I} - I_0}{T} - D_1. \tag{49}$$

By introducing the following labelling conventions

$$J_0 = I_0 - \tilde{I} + D_1 T - \widehat{D}\tau, \tag{50}$$

$$J_1 = \left(\frac{\tilde{I} - I_0}{T} - D_1 \right) \tau, \tag{51}$$

equations (48) and (49) can be transformed into the following system of algebraic equations containing complex coefficients to be solved for A:

$$A\, e^{W} = J_0, \tag{52}$$

$$AW\, e^{W} = J_1. \tag{53}$$

At this point it is useful to decompose A and W to their real and imaginary components

$$A = a + \alpha i, \tag{54}$$

$$W = w + \Omega i. \tag{55}$$

The $\Omega \neq 0$ case

First we assume, that W has a non-zero imaginary part, *i.e.* $\Omega \neq 0$. This scenario happens only when $\tau/T > 1/e$. Since we use complex quantities for the representation of the inventory, equation (52) represents two scalar conditions for the two components of A. Thus, no more degrees of freedom are left for setting the value of the slope. Since in the given framework the satisfaction of the imaginary part means no practical benefit, we can relax the full satisfaction of equations (52) and (53) and focus only to the real parts

$$e^w \left(a \cos\Omega - \alpha \sin\Omega\right) = J_0, \tag{56}$$

$$e^w \left[a(w \cos\Omega - \Omega \sin\Omega) - \alpha(w \sin\Omega + \Omega \cos\Omega)\right] = J_1, \tag{57}$$

respectively. The solution of equations (56) and (57) for the components of A is

$$a = \frac{J_0(\Omega \cos\Omega + w \sin\Omega) - J_1 \sin\Omega}{e^w \Omega}, \tag{58}$$

$$\alpha = \frac{J_0(w \cos\Omega - \Omega \sin\Omega) - J_1 \cos\Omega}{e^w \Omega}. \tag{59}$$

These solutions were properly obtained in [16]. However, equations (58) and (59) loose their validity when $\Omega = 0$. This case was not investigated by Warburton, claiming, that it leads to permanent inventory deficit. While it is most certainly the case under the present circumstances, in the following paragraph we give the details of this particular scenario because it opens up an unexplored class of solutions to the inventory equation.

The $\Omega = 0$ case

If $0 < \tau/T \leq 1/e$, then $\Omega = 0$, *i.e.* W becomes purely real. Now the real parts of equations (52) and (53) take the following, particularly simple form

$$a\, e^w = J_0, \tag{60}$$

$$aw\, e^w = J_1. \tag{61}$$

It turns out, that the real and the imaginary components of A are completely decoupled, thus, both equations (60) and (61) contain only a as an unknown, α does not appear. The solutions for a by equations (60) and (61) are, respectively

$$a = \frac{J_0}{e^w}, \tag{62}$$

$$a = \frac{J_1}{w\, e^w}. \tag{63}$$

Equations (62) and (63) can only be simultaneously satisfied if

$$J_1 = J_0 w. \tag{64}$$

Theoretically, for any meaningful combination of T and τ one can set I_0 and/or $\tilde{I}$ such, that equation (64) is satisfied. However, if I_0 and $\tilde{I}$ are given in an application, as it is usual, the satisfaction of equation (64) can not be guaranteed. In general, whenever $\tau/T \leq 1/e$ holds, the slope of the inventory can not be matched with its exact value at $t = \tau$, only the value of the inventory can be set. This clear deficiency of the present framework based on the principal branch of the Lambert W function is not given in the related references [16–19]. Indeed, the complex exponential approximation starts with the correct value at $t = \tau$, but its slope is incorrect. This feature predicts errors in the solution whenever $\Omega = 0$ holds.

4.4. Notes on the matching

The matching procedure described above is based on the practically relevant principle, *i.e.* setting the level of inventory and its derivative at $t = \tau$. We noted, that in general, the derivative of the inventory is discontinuous at this point. It is only continuous if the initial and the target inventory levels are equal, *i.e.* equation (1) holds.

In order to analyse some models presented in the literature, for $I_0 \neq \tilde{I}$ we shall investigate the consequence of improper matching based on the requirement of C_0 and C_1 continuity of the inventory at $t = \tau$. Even though condition (1) does not hold, C_1 continuity can be enforced by matching the approximate solution (44) with (42). This choice can be conveniently implemented by replacing equation (51) with

$$J_1 = -\widehat{D}\tau, \tag{65}$$

while all the following formulas stay unchanged.

5. Results

In this section we present the solution of test problems designed for highlighting the most significant properties of the complex exponential approximation. All cases derive from a single scenario considered by Warburton for demonstrating the accuracy of the model (see figure 7 of ref. [16]). The setup describes the startup of a distribution facility. Accordingly, for $t < 0$ orders are not issued, *i.e.* $O(t) = D_0 = 0$. The lead time is $\tau = 10$. Unfortunately, in the given reference the numerical value of the constant demand rate is not given, nevertheless, it can be guessed from the figure to be $D_1 = 20$. At $t = 0$ the facility starts its operation by replenishment policy (5) targeting $\tilde{I} = 1000$. The remaining parameters I_0 and T are case dependent and given below. Note, that Warburton plotted the results from $t = 0$ until $t = 50$, while we take a 20% larger interval with $t = 60$.

5.1. Oscillatory solution, $I_0 = \tilde{I}$

In the original test case detailed above $I_0 = \tilde{I}$, therefore the inventory is C_1 continuous at $t = \tau$. Here we consider only a single value of the adjustment controller, $T = 4$. The solution is given on the left of figure 2. The thick solid line represents the reference solution, computed by a simple Runge-Kutta method. Since the level of the numerical error is not visible on the scale of the plot, we can well consider it as the exact solution $\mathcal{I}(t)$. The thin solid line corresponds to the known preshape function for $0 \leq t < \tau$, continued by the approximate exponential solution starting at $t = \tau$. On the right of the figure the signed relative error is plotted:

$$\epsilon(t) = \frac{\mathcal{I}(t) - I(t)}{\mathcal{I}(t)}. \tag{66}$$

Observe, that the exponential approximation seems to closely follow the exact solution. Warburton even concluded that the error is less than 3%. However, figure 2 implies that the error grows to 15% if we extend our investigation beyond $t = 50$.

5.2. Oscillatory solution, $I_0 \neq \tilde{I}$

Now we slightly perturb the setup of the previous test case, and reduce the starting inventory by 10%, *i.e.* $I_0 = 900$. Since $I_0 \neq \tilde{I}$, the exact solution will be C_1 discontinuous at $t = \tau$, with a slope that is precisely captured by the approximate solution. The results are shown on figure 3. The thick solid line corresponds to the exact solution in the sense discussed above. The thin solid line represents the C_1 discontinuous solution, with the exact values of $I(\tau) = \mathcal{I}(\tau)$ and $dI/dt|_{t=\tau} = d\mathcal{I}/dt|_{t=\tau}$ imposed. The thin dashed line corresponds to the incorrect C_1 continuous solution at $t = \tau$. Observe the significant errors on the right figure. For the theoretically correct case the deviation is 32%, while the incorrect enforcement of C_1 continuity increases the error to 71%.

5.3. Non-oscillatory stable solution, $I_0 = \tilde{I}$

Now we turn our attention towards non-oscillatory solutions, when $0 \leq \tau/T \leq 1/e$. We take the limiting value of $T = e\tau$, resulting in $W(-1/e) = -1$. As in the original case, $I_0 = 1000$. Although the exact solution is C_1 continuous at $t = \tau$, the approximate inventory does not reflect this property as predicted in section 4.3.5. This feature is well demonstrated by figure 4. The highest deviation from the reference solution is 9%. Observe, that the asymptotic solution suffers from permanent inventory deficit with a magnitude of $D_1 T$.

5.4. Non-oscillatory stable solution, $I_0 \neq \tilde{I}$

Finally, we stay in the non-oscillatory domain with $T = e\tau$ and decrease the starting inventory to $I_0 = 500$. The solution is presented on figure 5. The discontinuity of the exact solution is well pronounced in this case. The highest deviation from the reference solution is 25%. The effect of permanent inventory deficit is clearly captured.

6. Discussion

The scope of the presented study is the analytic investigation of linear inventory control in the framework of DDEs. The corresponding theory has been developed in a series of papers by Warburton [16–19]. Although these studies are definitely progressive, certain avenues have not yet been explored, and some misconceptions have led the author to suboptimal conclusions. In order to improve the present status of the available material, in this paper we revisited the subject, focusing on [16] that introduced the formalism. For completeness we gave a detailed description of the basic solution procedure, that we extended by some additional derivations. In this section we discuss the main implications of the theory and the test calculations.

6.1. The approximate nature of the exponential solution

In references [16–18] it is emphasised, that the presented theory provides exact solutions of the inventory balance equation, without the need of approximations. This statement is true for the general solution. However, any particular solution has to satisfy the corresponding initial condition *exactly*, that is in fact a functional condition given by (8). In a practical example of [16], for $0 \leq t \leq \tau$ the particular approximate solution, that is a single complex *exponential* function, has to match *exactly* the *linear* pre-shape function, which is not possible. The only theoretical possibility to achieve an exact particular solution in the given framework is related to the specific case, when the pre-shape function is purely exponential. Thus, the complex exponential solution based on the Lambert W function is in fact an exact analytic *approximation* to the particular solution defined by inventory equation (4) *and* initial condition (8).

6.2. Accuracy of the exponential approximation

Reference [16] provides the following conclusion: *"In practical situations where there is likely to be noise in the data, the one-term Lambert W function provides an easy-to-compute, accurate representation of the inventory response."* As a supporting example, figure 7 of [16] displays plots containing both the reference solutions and the exponential approximations. In those particular cases the error is claimed to be less than 3%. However, in section 5 we extended the integration time of the very same test case by 20%, and found, that the relative error rapidly grows to 15%. If we let the starting inventory to differ from the target inventory by only 10%, the error climbs to 30%, that is not considered to be small anymore. In conclusion, we contradict to references [16–18] by stating, that the error is very much dependent on the parameters and on the integration time, rendering the model highly inaccurate at certain occasions.

6.3. Dependence on τ/T

Reference [16] concludes: *"Treating A as a complex constant results in a solution that turns out to provide an excellent representation of the inventory over the entire range of τ/T."* As we pointed out in paragraph 4.3.5, this procedure works well if the imaginary part of W is not vanishing. However, in domain $0 \leq \tau/T \leq 1/e$ W is purely real, thus we can only match the level of the inventory at $t = \tau$, and we have no control over the derivative. This fundamental difference can lead to the appearance of considerable errors as justified by the results of section 5, especially if equation (1) does not hold.

6.4. The C_1 discontinuity of the inventory at $t = \tau$

It is somewhat surprising, that in [16–18] the matching conditions are derived by targeting both C_0 and C_1 continuity of the inventory at $t = \tau$ for the complex exponential approximation. Indeed, in [18] we find: *"To determine A, we recognize that the inventory and its derivative must be continuous at $t = \tau$."* Equations (45) and (46) of the present paper imply that this statement is incorrect. The derivative of the inventory is continuous at $t = \tau$ only if

$$D_0 = \frac{\tilde{I} - I_0}{T}, \tag{67}$$

otherwise it is necessarily discontinuous. Thus, a more appropriate philosophy for obtaining constant A is to set both the level of the approximate exponential and its derivative to their respective exact values at $t = \tau$. In figures 3 and 5 we present solutions with $I_0 \neq \tilde{I}$. The non-continuity of the exact solution is apparent. Although equation (1) does not hold, the slope of the exponential approximation may still be forced to be continuous, regardless of the fact, that theoretically it is incorrect. This choice leads to an undesired undershoot followed by a phase shift, increasing the relative error above 70% in one particular example. On the other hand, if the inventory and its derivative are matched with their exact values at $t = \tau$, the approximate exponential starts at the proper level with the right slope. In this case figure 3 presents exaggerated overshoots around the maxima and an error function increasing above 30% at certain instances. Another interesting approach to determine constant A could be to analytically minimize integral (47).

7. Concluding remarks

The analytic investigation supported by computational evidence presented in this paper contradicts to the literature. In particular, references [16–18] conclude that the complex exponential approximation based on the principal branch of the Lambert W function provides an easy-to-compute, accurate representation of the inventory response. By applying slight perturbations on the setup of a single test case in [16] we found, that the accuracy of the analytic approximation is sensitive to the choice of the model parameters and the integration time. The relative error varies over a wide range, reaching even 30%, which is not acceptable in most applications. Clearly, a careful parameter study could reveal even much higher errors. It is not a surprising conclusion though, considering the fact that the solution of a DDE is approximated by one single complex exponential. In all the test cases of [16–18] it is assumed, that initially the inventory is at its target value. We released this assumption, since in real life it can not always be accommodated. Numerical examples imply considerable deviations from the unknown exact solution in this case, revealing a definite limitation of the model.

The accuracy is expected to increase by including more modes in expansion (37), as proposed by Warburton and Disney [19]. Due to the lack of corresponding convergence analysis the approximation has to be verified by a fairly simple numerical integration procedure representing the exact solution with a very high accuracy. If so, the question naturally arises: what is the point of the analytic efforts in increasing the accuracy, if the numerical solution is extremely fast, reliable and accurate? Perhaps the most benefit can be gained from the investigation of the single exponential approximation based on the principal branch of the Lambert W function. Indeed, it is relatively simple to manipulate, and most results can be obtained in closed analytic form. It seems, that the scope of the presented methodology has its most value in the stability analysis of the inventory balance equation. Indeed the principal branch has the strictest stability condition that is embraced by the stability condition of the other branches [1]. The corresponding formula limits the ratio of the lead time over the adjustment time to $0 \leq \tau/T \leq \pi/2$ for getting a stable response. It also provides hints to what parameter values to choose in order to avoid the generation of oscillatory orders by a steady demand.

Starting from the concepts discussed above we explored the behaviour of the exponential approximation in the parameter domain corresponding to stable non-oscillatory solutions. As an example, we studied the inventory response to a sudden increase in the demand followed by a constant state. From the point of view of inventory management non-oscillatory decaying solutions could be preferable over oscillatory ones. Surprisingly, the *optimal* ordering policy proposed by Warburton [16–18] positions the system in the stable *oscillatory* domain by claiming, that non-oscillatory solutions are prone to permanent inventory deficit. This defect is induced by incomplete ordering policies neglecting the so-called demand term. However, inclusion of this term removes the deficit and opens up the path to stable non-oscillatory solutions of the inventory balance equation. This will be the subject of our upcoming publication.

Acknowledgements

The paper was supported by GOP-1.1.2-07/1-2008-0003 European Union and European Regional Development Fund joint project in the framework of Car industry, Electronics and Logistics Cooperative Research Center of Universitas-Győr Nonprofit Ltd.

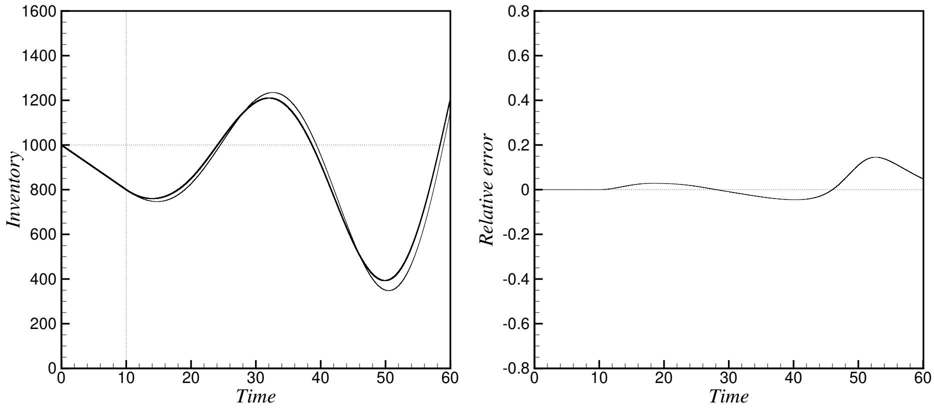

Figure 2: Inventory response in the oscillatory unstable domain. The parameters are: $\tilde{I} = 1000$, $I_0 = 1000$, $D_0 = 0$, $D_1 = 20$, $\tau = 10$, $T = 4$. Thick solid line: reference solution. Thin solid line: exponential approximation. Left side: inventory response. Right side: relative error of the approximate solution ($|\max \epsilon(t)| = 15\%$).

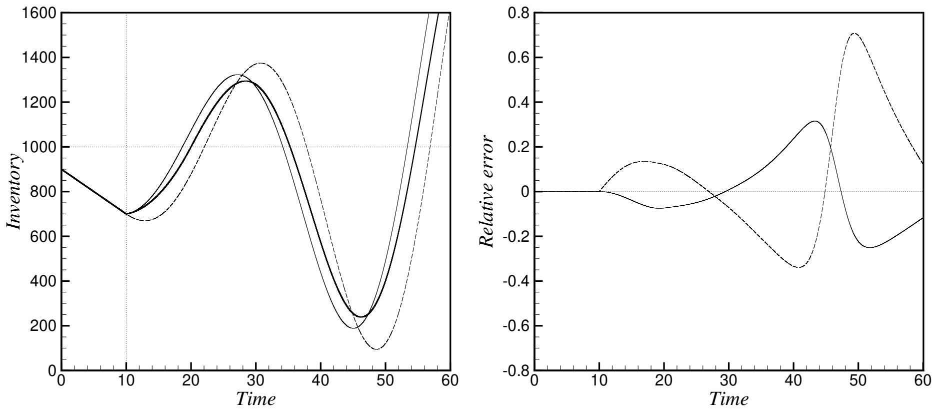

Figure 3: Inventory response in the oscillatory unstable domain. The parameters are: $\tilde{I} = 1000$, $I_0 = 900$, $D_0 = 0$, $D_1 = 20$, $\tau = 10$, $T = 4$. Thick solid line: reference solution. Thin solid line: exponential approximation with C_1 discontinuity ($|\max \epsilon(t)| = 32\%$). Thin dashed line: exponential approximation with C_1 continuity ($|\max \epsilon(t)| = 71\%$). Left side: inventory response. Right side: relative error of the approximate solutions.

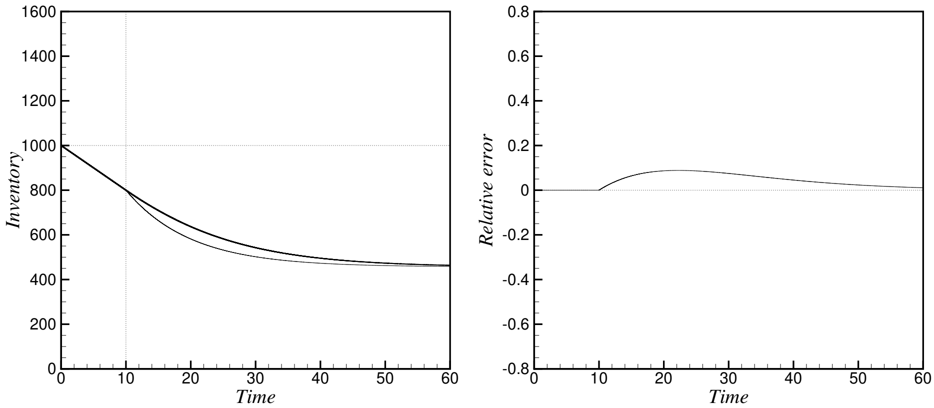

Figure 4: Inventory response in the non-oscillatory stable domain. Thick solid line: reference solution. Thin solid line: exponential approximation with C_1 discontinuous inventory. The parameters are: $\tilde{I} = 1000$, $I_0 = 1000$, $D_0 = 0$, $D_1 = 20$, $\tau = 10$, $T = e\tau$. Left side: inventory response. Right side: relative error of the approximate solution ($|\max \epsilon(t)| = 9\%$).

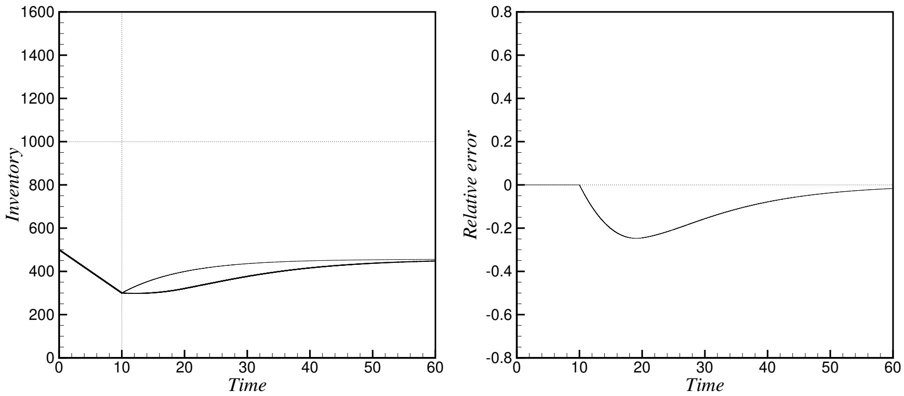

Figure 5: Inventory response in the non-oscillatory stable domain. Thick solid line: reference solution. Thin solid line: exponential approximation with C_1 discontinuous inventory. The parameters are: $\tilde{I} = 1000$, $I_0 = 500$, $D_0 = 0$, $D_1 = 20$, $\tau = 10$, $T = e\tau$. Left side: inventory response. Right side: relative error of the approximate solution ($|\max \epsilon(t)| = 25\%$).

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Packaging Unit Quantity Optimization

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Abstract The level of cooperation between suppliers and manufacturer has serious effect on cost price of the final product. Several factors - like the packaging type of supply materials, the packaging unit quantity, the schedule of shipments, etc.– depend on the flexibility of vendors. However vendor attitude depends on the relationship between business partners. This paper discusses the case when the manufacturer has the possibility to request the vendor to define packaging unit quantity according to its own claim without rise in prices; changing packaging unit quantity may cause significant decrease of additional production costs. To determine optimal quantity on packaging units the following logistic trade-off should be solved: on the one hand extra material handling cost may emerge; on the other hand inventory keeping cost may grow.

Keywords: packaging unit quantity, inventory level, material handling cost, production supply

1. Introduction

One pillar of JIT (Just in time) philosophy in automotive industry is kanban control by which pull ordering can be achieved both on supply chain level and within production system. In pull system supply process starts as the result of consumption – or estimated consumption on intercompany level – in order to avoid accumulation of inventory.

However Toyota production model professionals emphasize that JIT should not have priority over reasonable utilization of manufacturing systems; in many cases it is not economic to produce in the pace of partner or costumer consumption. It may prove to be more advantageous to smooth manufacturing system capacity and keep higher utilization and use certain quantity in buffer. As a consequence of this alternatives of kanban appeared like CONWIP [7].

When searching the most proper way to operate a system we face many trade-offs to solve [4]; in practice it is more like an iteration procedure – that is why a new-born manufacturing system is rarely optimal.

Before new product appears on market thorough consultation and cooperative process runs along the supply chain. Beside technological implementation of products the planning of logistic processes runs parallel.

Selection of vendor partners, transportation modes and routes, packaging development, information exchange definitions, etc. are all the part of new product introduction. On such level of inter-company relationship the selection of proper packaging unit quantity is rated as routine agreement among selection of several other parameters [6].

The aim of this paper is to solve a trade off - from packaging unit quantity point of view - between stock keeping cost and material handling cost considering parallel assembly lines supplied by kanban control system.

Parts delivered to production line are physically associated with kanban cards which indicate:

- Part number
- Kanban quantity
- Identifier of production line where effective consumption took place

Besides data above other additional data may be indicated on kanban cards:

- Name and/or photo of part number in order to ease identification of parts
- Warehouse location in order to ease picking
- Barcode attached to any of the above mentioned data

By kanban control in production area the inventory level can be kept on a constant level at assembly lines [1]. Reorders are generated in the pace of consumption this way inventory lack or accumulation is eliminated – at least in theory and in case kanban quantity is well calculated [3], [10]. That is the cause why kanban became the basis of lean production [1].

Generally in manufacturing systems with kanban control the following material handling (line replenishment) process can be observed:

1. Production line operator opens a new packaging/kanban unit – removed from line buffer
2. Operator places kanban card in a dedicated bracket or shows the card barcode to scanner, etc.
3. Production line loader operator collects kanban cards / electric kanban sign is sent to IT system
4. Components are picked from warehouse
5. Parts are transferred to production lines.
6. Line is loaded by operator: packaging units are placed in line buffer.
7. After first content of a packaging unit is used up by assembly operator kanban order is generated.

In a manufacturing system with developed identification and information system historical data can be easily collected since date and time data is usually registered to each transaction type [2].

Simulation techniques often provide only iterative tool for finding optimum solution of logistic trade-offs. In previous researches the question of unpacking in production plants had been analyzed by the application of simulation software [9]. By changing input parameters of simulation we can give better but not optimal solution of packaging unit quantity; by creating simple mathematical models optimal solution can be achieved.

The question of packaging unit can be traced back to the basic EOQ model introduced in the beginning of the 20^{th} century [5]. The model of Economic order quantity solves the trade-off between ordering cost and inventory holding cost.

2. Model formation

In the followings the mathematical model is introduced: first a general model is described, then the input and output parameters are listed. After that a mathematical model is set up. The last part of the model description is a case study to demonstrate the operation of the model.

2.1. Model description

The schematic model of the plant is demonstrated on Figure 1.

The application of the model presumes that the plant is divided into two segments: a warehouse and a production area. Materials used up in the production area are replenished from warehouse; replenishment is the task of line loader operator.

We assume a traditional kanban system where cards sign the consumption of packaging units and generate replenishment order. After picking – which lasts for T_{pick} - the indicated kanban quantity is taken to the production line. The operator spends T_{in} time on leaving the warehouse and arriving to the first production line. The loading of the work station lasts for T_{load}. Parts have to be taken to M number of production lines; the transfer time between lines is $T_{transfer}$. The route between the last production line and the picking area lasts for T_{out}. Operators get c_{wage} payment for material handling.

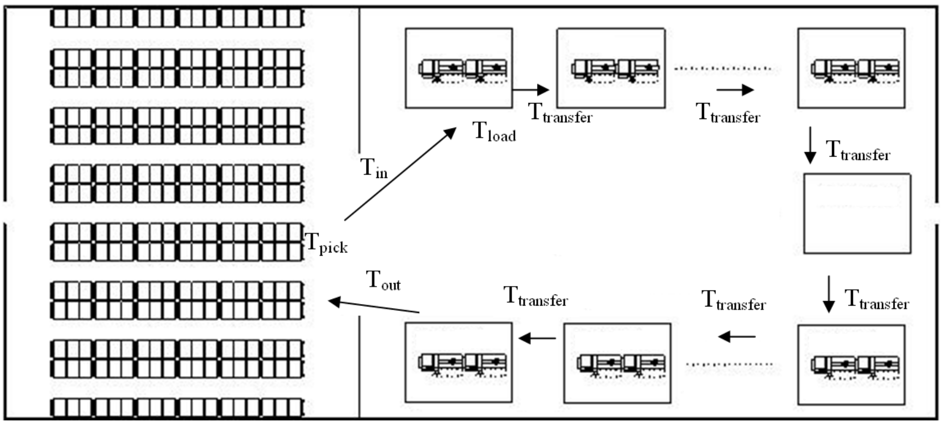

Figure 1. Schematic model

At each production line - operating with T_{cycle} cycle time - p pieces of parts are built in a final product. During Δt time interval N number of kanban cycles has to be done; so that the total replenishment process should be repeated N times.

The increase of average inventory level (I_{avg}) with a single part at a single production line causes c_{hold} extra holding cost; since it does not produce interest and causes extra material storing needs.

We assume that cooperative relation with the vendors allows the variability of the packaging unit quantity (q); the aim is to define its optimal value (q_{opt}) where total cost ($C(q)$) is minimal.

The kanban quantity should not be less than the consumption of a production line (q_{min}) during the kanban cycle time (T). If the physical features of parts allow setting up smaller packages than minimal kanban quantity then more packaging units should be transferred to production line at the same time.

Regarding the system description above the following parameters can be distinguished:

Table 1. Parameters of mathematical model

Symbol	Test value	Test value	Type	Description
Δt	176	h	chosen value	Length of examined productive time period starting at t_0 and ending at t_1
N	139,3	pcs	calculated value	Number of required kanban cycles during the examined period
c_{wage}	3	EUR/h	chosen value	Wage of material handling operator
M	10	pcs	chosen value	Number of production lines where examined part is used up parallel
c_{hold}	$8 \cdot 10^{-7}$	EUR/yr/pcs	measured value	Inventory holding cost – this is calculated by controlling tools; it contains storage costs and the wastage caused by the fact that fund is bound and does not produce interest
I_{avg}	999	pcs	calculated value	Average stock level of each production line
q_{min}	0,991	pcs	calculated value	Minimal kanban quantity
T_{pick}	5	min	measured value	Picking time
T_{in}	1	min	measured value	Transfer time from picking place to first production line
T_{load}	0,5	min	measured value	Production line loading time
$T_{transfer}$	0,2	min	measured value	Transfer time between production lines
T_{out}	1	min	measured value	Transfer time from production line to picking place
T_{cycle}	0,1	min/pcs	measured value	Production line cycle time
p	1	Pcs	chosen value	Number of pieces used for one final product assembly
T	13,8	min	calculated value	Kanban cycle time
q	variable	pcs	chosen value	Optimization parameter
q_{opt}	758	pcs	calculated value	Optimal packaging unit quantity
C(q)	variable	EUR	calculated value	Total cost of supply material handling and storage

2.2. The mathematical model

The total kanban cycle time contains the picking time, travelling times between warehouse and production area, production line loading times and transferring ti3me between production lines. Regarding that *M* number of lines should be filled the following equation can be set up (1).

$$T = T_{pick} + T_{in} + T_{out} + M \cdot T_{load} + (M - 1) \cdot T_{transfer} \tag{1}$$

The replenishment process has to be repeated *N* times depending on the length of the examined time period, the number of parts building in a final product, packaging unit quantity and production line cycle time (2). If the number of kanban cycles is known the total productive time that should be spent on material handling during Δt can be calculated.

$$N = \frac{\Delta t \cdot p}{q \cdot T_{cycle}} \tag{2}$$

In this model those cases are neglected where packaging unit quantity is smaller than minimal kanban quantity. Minimal kanban quantity equals to part consumption during the replenishment period and can be calculated according to (3), packaging units with smaller quantity are not taken into consideration in this model.

$$q_{min} = \frac{p \cdot T}{T_{cycle}} \tag{3}$$

Figure 2 shows the run of inventory at single production lines. Right after a packaging unit is opened by production operator a kanban card is placed on a dedicated kanban collection bracket or a flag is drawn up. This is the reorder point and in our case inventory level equals to the packaging unit quantity. Electric kanban reordering means that material order appears on the screen of the picking operator's mobile data collector; this way the previously mentioned T_{out} input parameter is 0.

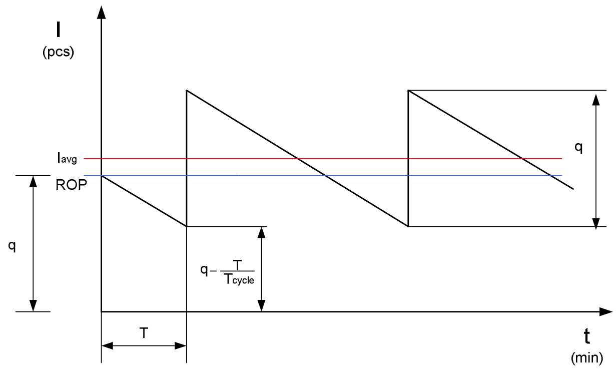

Figure 2. Inventory diagram of single production lines

As the result of kanban control system the reordering point equals to the kanban quantity which practically equals to packaging unit quantity. Since reordering starts almost right after start of consumption after $\frac{p \cdot T}{T_{cycle}}$ number of components is used up new supply material - which equals to q - is loaded to production line. The average inventory level can be calculated as in (4).

$$I_{avg} = \left(q - \frac{p \cdot T}{T_{cycle}} \right) + \frac{q}{2} = \frac{3}{2} q - \frac{p \cdot T}{T_{cycle}} \tag{4}$$

If average inventory level of a single production line, the number of production lines, the holding cost of one part, the length of the examined interval is known the function of the inventory holding cost can be set up. By using up previously calculated number of kanban cycles, the productive time of material handling in a single kanban cycle and knowing the fee of operators the total material handling cost can be calculated. Let us create a total cost function that contains both material handling and inventory holding costs (5):

$$C(q) = N \cdot T \cdot c_{wage} + M \cdot c_{hold} \cdot \Delta t \cdot I_{avg} \tag{5}$$

After using up (2), (4) and (5) the following cost function can be set up (6).

$$C(q) = \frac{A}{q} + B \cdot q + D \tag{6}$$

Where A, B and D parameters cover the following formulas:

$$A = \frac{p \cdot T}{T_{cycle}} \cdot T \cdot c_{wage} \tag{7}$$

$$B = \frac{3}{2} \cdot M \cdot c_{hold} \cdot \Delta t \tag{8}$$

$$D = -\frac{M \cdot c_{hold} \cdot \Delta t \cdot T \cdot p}{T_{cycle}} \tag{9}$$

The aim was to compute the optimal size of packaging units arriving to the production plant. The optimal packaging unit quantity can be defined by (10).

$$\frac{dC(q)}{d(q)} = 0 \tag{10}$$

By solving the previous equation:

$$-\frac{A}{q^2} + B = 0 \rightarrow q = \sqrt{\frac{A}{B}} \tag{11}$$

Optimal solution can be found where the sum of material handling cost function and inventory holding cost function has minimum value (Figure 3.). If we watch the characteristic of the cost function similarity with EOQ model cost function can be observed.

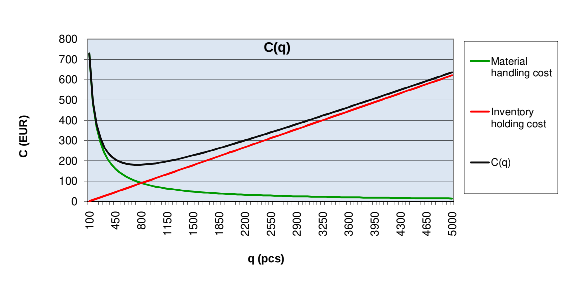

Figure 3: Total cost in function of packaging unit quantity

3. Case study

The presented mathematical model with parameters given in Table 1 optimal packaging unit quantity turned out to be 758 pieces by which the realized cost is 180,522 EUR/month; costs may be multiplied if packaging unit quantity is changed. Regarding that we analyze the cost conformation of only one part this opportunity hide significant cost saving.

Packaging unit size could have greater importance in case of small and relatively expensive components used by two or more production lines.

Packaging unit quantity	Material handling cost	Inventory handling cost	Total cost
100	728,64	1,01	729,65
150	485,76	7,35	493,11
200	364,32	13,69	378,01
250	291,46	20,02	311,48
300	242,88	26,36	269,24
350	208,18	32,69	240,88
400	182,16	39,03	221,19
450	161,92	45,37	207,29
500	145,73	51,70	197,43
550	132,48	58,04	190,52
600	121,44	64,37	185,81
650	112,10	70,71	182,81
700	104,09	77,05	181,14
750	**97,15**	**83,38**	**180,53**
800	91,08	89,72	180,80
850	85,72	96,05	181,78
900	80,96	102,39	183,35
950	76,70	108,73	185,42
1000	72,86	115,06	187,93
…			

Table 2. Cost level at different packaging unit quantities

4. Conclusion

The structure and operation of production supply systems directly influence cost price of the final product. This model gives a simple solution how to minimize the total additional cost (inventory holding and material handling cost) by changing one parameter to optimal level.

In order to ease modeling the system specification neglects several influencing factors:

Real stochastic processes are described by deterministic processes (line loading process, production cycle times, etc.); this negligence has serious effects on system behavior [8] it needs to be worked out in the future. We assume that right after consumption kanban order is taken by line loader operator; waiting time is not considered but could be significant and depends on current position of line loader operator. All these conditions could move optimal solution.

It is the challenge of further researches to integrate the effects of these factors into the model. Further researches aim to determine optimal unpacking quantities in case unpacking station is inserted between production lines and warehouse.

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The Possibilities of the Performance Measurement to the Estimating of the to Logistic Processes Joining Supplementary Work Hour Demand at the Automobile Manufacturer Factory

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Abstract I classify in my paper to the production batches connecting necessary of supplementary work at a special car manufacturing Supplier Company, and I identify the nature of production batch sizes. Due to the industry's features the logistic processes have been broken down for small-, medium and mass production batches. Even without an articulate analysis a larger batches seems more lucrative and efficient. Comparing to the others, the small-serial production sporting a higher profits per products, thus a proceeding of a more accurate analysis is justified. To prepare the decision it have to carefully studying such other features of the special logistic-manufacturing conditions such as the complexity and number of the production phases, the given products routing times and so on. The Balanced Score Card system is widely accepted in the analysis of these processes, and in preparing the strategic decisions. According to my measurement and date I describe a multi-criteria and multi-dimensional cluster analysis tool for better forecasting of supplementary work demand related to new processes.

Keywords: Balanced Score Card, system identification, production planning, performance measurement, cluster analysis

1. Introduction

The changing business environments have a growing impact on manufacturing system requirements. Decreasing product lifetimes and batch sizes result in forecasts poor quality, lower technological reliability in terms of quantity and time horizon. New manufacturing processes or row materials might require adaptations or changes to the machines.

Machines and technological systems are capable of dealing with changing requirements then this is only in a very limited range and requiring much time and effort. These are the reasons, why reconfigurable manufacturing systems are designed for specific operations at high throughput; they represent cost-efficient and effective manufacturing devices [1].

The goal of process planning in a production environment is to select and define, in detail, the process involved in transforming raw material into a specific end product with a given shape and certain specifications.

To determine the feasibility of processes and operations, together with the necessary parameters, assure the finished manufactured part is obtained without any problems. The purpose of production planning and control (PPC) is optimising the flow of material and the use of the machines involved in manufacturing, taking into account various management goals like reducing the work in progress, minimising shop floor throughput and lead times, improving responsiveness to changes in demand and improving delivery date adherence. Typical production planning and control system functions include planning material requirements, demand management, capacity planning and the scheduling and sequencing of jobs.

Both process planning and production planning have complementary goals in order to improve continuing company productivity and, eventually, competitiveness. Process planning concerns and requires detailed information about the process – it is crucial to develop an appropriate model that can be applied in the integrated process planning and scheduling. The usual way to divide up process planning tasks in manufacturing companies is to hand over the plans to the manufacturing process experts who then specify the procedures to make the product: the planner's knowledge of production planning is fundamental [2].

Key factors to remain competitive in the manufacturing business is the effective and efficient operation of installed manufacturing systems, as well as the ability to quickly and easily re-configure these systems, for instance in the case of new product introduction.

Simulation engineering is an enabling technology for life-cycle decision support. However, simulation is often used as a stand-alone tool for design and configuration of production facilities, or for off-line programming - simulation tools offer even more benefits and better decision support when connected to the production facility on-line [3].

The objective of my research is to reveal the nature of production processes, to determine the prospective failures, to forecast the supplementary work hour demands, for reaching the minimal failure level in the production system at a car manufacturing Supplier Company.

The company prepares different parts for different types of cars and of course as a car component manufacturer they have to be equal to the high demand from the sector - in this case I am talking about an extended supply network and it is quiet a challenge to keep the balance in the whole supply chain.

The car parts are made from aluminium through different production processes. The production procedures involve all parts of the procession. Indeed, this would cover the three big parts: the processing of materials, the labour work and the finished product manufacturing.

The processing of row materials equals the cleaning, cutting (cut to size). The labour works involve the bending, traction, draw-bending, cut-out, squeeze. The finished product manufacturing means the milling, heat treatment and the starch process.

There are several failures and significant amount of supplementary work related to these failures today – in my paper I made an attempt to discover the relations between them.

2. Failure analysis in the literature

The current production process has significant amount of producing failures. In order to get the best solution to avoid producing failures the first step should be the determination of the causes and reasons of these failures.

The main types of failures from the viewpoint of origins are human and machine failures.

2.1. The human factor, as source of failures

The human factor is a major issue when optimizing manufacturing systems. Management has the responsibility to plan and specify the production tasks and to monitor the performance delivered, while workers have to execute plans in precise accordance with the specifications given. The knowledge of motion analysis is supplemented with ergonomic or human factor knowledge - the core is a set of criteria to be met if a workplace and a job shall fit the man performing the job [4].

The human factor is not comparable to other production factors. There are contradictions on the fields of acceptable and necessary variations at a given work tasks, the ability and request of learning during the task, and being able to make work-related decisions on different levels with responsibility. In the same time there is a need for a certain amount of mutual respect between the humans involved, a need to experience a relation between work and what is considered of value in society, and a need to see the job compatibility in a desirable future [4].

2.2. Mechanical sources of failures

From the machine failure viewpoint the objective is to develop methods for monitoring the failures to manage progressive failures [5].

Cataleptic failures are failures that cannot be detected by process inspections achieved by maintenance operators; they are sudden and complete. At the opposite, progressive failures characterise degradations occurring in a process. Consequently, they are partial.

2.3. Analysis of the production process

The main functions of monitoring are detection and diagnosis. Detection is also shared in sub-functions: data acquisition, data validation, detection of process failures (also called decision), and failures classification.

Diagnosis is generally broken down to three sub-tasks: localisation (to find a functional sub-set of failing process components), identification (to refine localisation by identifying the origin of a failure), prognosis (to determine the inescapable consequences of a failure and to analyse its potential consequences, to prepare data required by the error recovery task) [6].

Human failures are coming from machine settings problems (re-setting), from the failures of raw material quality check, and also perception problems of surface quality, like burr (flash).

Machine failures are coming from settings changes, breaking down and degradation of tools (devices).

The opinion of the company is that the bending and the labour work are the most fraught with risk. The company manufacture many kinds of products in different amounts, batches and series, and frequently changing orders induces errors and faults in the system which depends on the volume.

3. Application of BSC for performance measurement

Performance measurement systems (PMS) are important in many different functional areas of management, such as operations, marketing and sales or sustainability [12].

PMS can be a form of diagnostic controls through measurement of actual results: such systems can focus employees on specific results that are expected from them and make them work harder and put in more effort. Those of expectations, which been specified by this way as well its obvious and positive definition will prompting a more accurate work and increased efforts.

Performance measurement systems (PMS) serve different functions. These are formal devices for control, and for the formulation and communication of strategy, and as such PMS primarily serve higher-level managers. But we can also aspire PMS to support operational managers, to motivate and enable these managers to improve operations.

3.1. The BSC and the human factor

The development of a performance measurement system could be a success if it is constructed as an enabler of performance improvement, rather than merely as a control device. For better acceptance and employee ownership it should have been experience-based, with allowing experimentation and built on employee's professionalism.

In operation the PMS should have been transparent for all participants and outside facilitators, under continuous revision and development from all sides. Propose that internal and external transparency, flexibility, and repair are characteristics of the system that contribute to the enabling nature of it [7].

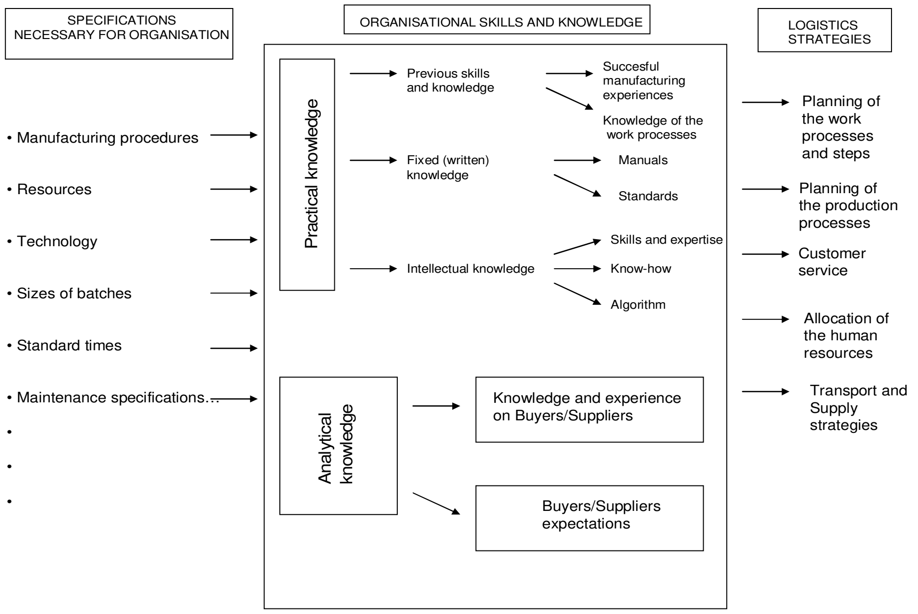

Figure 1. Role of the human resources during the establishing of the production-logistic strategies (Source: Author's study, based on [8])

At the process and operation it has to ensure full transparency for the system every single participants and active player. Thus the interior and exterior transparency, flexibility and the possibilities for the correction became the integral parts of the system.

3.2. The development of the performance measurement

The development of the performance measurement is a dynamic process – the very first steps are scarcely suits to the realisation of the desirable targets. Thus shall be important

– instead of the rigid, given solutions - the application of the flexible systems. The design, planning and running of the system shall be iterative - and not a linear one.

The flexible systems are prompting its users to accordingly modify and alter the leverages of the performance measurement and add to them such functions and "tools" which suits more to the particular and local features and work conditions. At the performance measurement for the sake of the flexibility and the transparency it have to able the employees to participate in the running and management of the PMS as a structural system. Due to the flexibility and the transparency the Associates will have a better understanding of the performance measurement, since by her/his own active practical experiences they can interact – they can "feasibly" influence its structure, outputs.

Empirical studies have found that operational strategies such as JIT, quality improvement and flexibility, make it relevant to expand traditional efficiency-focused performance measures and to embrace new performance measures [6].

Financial performance measures continue to be an important aspect of management accounting, although these are being supplemented with a variety of non-financial measures what are more actionable than aggregate financial measures, and they provide more direct insights into the causes of good or bad performance.

The management team usually works only a limited number of performance measures, mainly overall delivery reliability, but there are also detailed measures zooming in on different performance dimensions, separate periods, and organizational sub-units.

Mainly they using overall delivery reliability, but besides these, if it is necessary – in case of given sub-tasks or analyses of given processes - they applying detailed measures zooming in on different performance dimensions, separate periods, and organizational sub-units.

3.3. The establishment of BSC

The BSC is a management tool composed of a collection of measures, arranged in groups, and denoted as cards [8].

The BSC was first proposed by Kaplan and Norton as a methodology aimed at revealing problem areas within organizations and pointing out areas for improvement. It was also promoted as a tool to align an organization with its strategy, by deriving objectives and measures for specific organizational units from a "top–down" process driven by the mission and strategy of the entire organization.

It was motivated by the realization that traditional financial measures by themselves are inadequate in providing a complete and useful overview of organizational performance. The measures are related to four major managerial perspectives, and are aimed at providing top managers with a comprehensive view of their business. The cards offer a balanced evaluation of the organizational performance along financial, marketing (customer-related), operational (internal-business processes) and strategic dimensions (learning and growth).

3.4. The areas of performance measurement (?)

The financial perspective examines the bottom-line contribution of the project in monetary terms. It reflects the profitability, cash flow, cost vs. budget, etc. The financial objectives serve as the focus for the objectives and measures in all the other scorecard perspectives.

Every measure in the scorecard should be part of a cause-and-effect relationship to improve financial performance. Many researchers have criticized what they perceive as an overemphasis on achieving and maintaining short-term financial results that can cause a bias towards investing in projects with short-term benefits, leading to insufficient investments in projects with long-term value creation. To overcome this obstacle, the BSC presents four other perspectives that ensure a more balanced evaluation of the project.

The customer perspective looks at the market value of the project deliverables, as well as stakeholder satisfaction with the final outcomes. The customer is interested in the responsiveness, timeliness, service and quality that the project provides. This perspective can include measures could be taken from customer surveys, focus groups, complaints, delivery statistics, etc. The question to ask is “how successful are the projects from the point of view of the customer?” Time to market, quality, and performance, as well as the way the customer is treated and the way his expectations are satisfied, are all relevant to evaluate the projects.

The internal-business processes perspective measures the contribution of the project to the core competencies of the organization. It addresses the degree to which the proposed project supports the organization’s mission and strategic objectives.

It is assumed that the top management has determined the strategic direction of the organization beforehand. Thus it would be necessary to measuring the compliance of the function of the structure to the objectives pursued. Beside of the measures it’s expected to be a “leverage of the compliance”, hence would be possible to fulfil the requirement of the iterative adjustment. The strategic assimilation may be expressed as the degree of assimilation from the strong to the weak/light.

If the organization wants to expand its range of core capacities into a new field, it must establish specific measures to reflect this. When the decision preparation is poor, the development project must be rejected or the strategy must be rethought. Otherwise, the fit level, be it strong, good, moderate or only peripheral, must affect the overall measure of the project’s attractiveness.

The objective in the learning and growth perspective is to provide the infrastructure to enable the objectives of the above three perspectives.

In today’s global competitive environment, organizations are constantly looking for further performance improvements to keep pace with competition.

When the evaluation is solely based on the short-term financial perspective, it is often difficult to sustain investments to enhance the capability of the human resources, systems, and organizational processes.

Hence, this perspective looks at the long-range growth impact of the project. The measures it includes (like propriety position) check whether the project is a platform for growth, and look at the durability of its effects.

BSC combines financial and operational measures, and focuses both on the short- and long-term objectives of the organization. Many organizations have adopted the BSC approach to accomplish critical management processes, clarify and translate their vision and strategy, communicate and link strategic objectives and measures, plan and align strategic initiatives, and enhance strategic feedback and learning. Projects, for the purpose of BSC, can be considered “mini-organizations” requiring the same clarifications and benchmarks as the parent organizations that are executing them. In fact, because projects are typically more structured than organizations, they are even more suitable for evaluation.

3.5. The application of BSC

The objective of the development a comprehensive BSC measurement system is to support the evaluation process during the different stages of a project’s life cycle. At the selection phase, where project proposals are evaluated, the BSC could be useful to clarify and translate the vision and strategy of the organization, and to set the appropriate criteria for a project’s attractiveness. Measures in this case would usually be forward looking, representing what is expected from these projects.

At the planning phase, the scorecard might be used to set targets, align projects with organizational strategy, and allocate resources within and among projects.

At the execution phase, the BSC could be instrumental in providing a relative measure of performance, evaluating the value of the projects in the face of changing circumstances and priorities, and communicating the results throughout the organization. The measures in this case would be a mix of forward-looking measures and backward-looking measures that represent what has already been accomplished. Finally, at the closing phase, the BSC can be used as a method of inquiry to identify best practices, and promote continuous learning.

The BSC model consists of two hierarchical levels: the cards and the measures. A key component to any BSC is the baseline or benchmark against which performance is measured. Without a standard or a baseline, evaluation is impossible. Once a baseline for evaluation is determined, the evaluation is done against the benchmark and the targeted plans[9]

It is hard to asses the objective value pursued. If the given/set value is false then they could be deceptive – the keystone is to have a thorough knowledge on the whole system’s features and reactions.

The performance –measuring Balanced Score Card system is involve the identification, understanding, documentation and assessment of the processes, as well the accumulated knowledge and experiences of the system – yet it bearing in mind the relevant aspects of the performance.

To arrive at a measure that is a valid, useful, and understandable indicator of performance in a specific local context. Researchers in operations management have argued for PMS that are multi-dimensional (with different kind of measures, on service, inventory, speed, cost, etc. and with a good understanding among these) and cross-empire [12].

4. The cluster analysis

Decision problems are widely differentiated in terms of the nature of solutions that should be found and the methods that can be used to solve them. One of the biggest and most complicated decision problems is the multi-criteria sorting which refers to problems in which any object to be classified or sorted is described by a set of criterion functions.

The process of collecting a set of objects into classes of „similar" objects is called clustering [10].

A cluster is a group of objects that are similar to one another within the same class and are dissimilar to the objects belonging to other clusters. Since multi-criteria sorting is considered as a particular case of classification problems, multi-criteria preference clustering should be distinguished from conventional clustering.

A clustering process is important when trying to determine classes of objects that are sufficiently alike as to share some given properties. The relevance of multi-criteria ordered clustering arises when the objects are described by criterion functions, that is, a preference ordering is defined by each attribute; hence, the classes that are derived from the clustering process should be ordered in a preferential manner, and the grouping itself should have a preference content.

Preference oriented cluster analysis requires preference informations (profit max, supply max, supplementary work hours min, etc.) should be provided by a decision agent, or elicited from some sorting examples.

Once clusters have been found, there are different ways to establish a ranking of the set of clusters, thus ordering the groups derived from the clustering processes. This is an implicit definition of categories that may be used for sorting purposes.

The way based on considering a strict preference relation on the set of cluster centres combined with the information coming from the cluster net flow score, performed very well in examples with characteristics of real life. Once the clusters have been ranked, the decision-maker and the analyst may accept this ranking as an implicit definition of a set of categories, or they may use some additional information in order to define the classes and the way in which the clusters are assigned to those categories.

4.1. The cluster's application in our case

As mentioned above the clusters have to be cross-checked but we have to create clusters of each failure and of the supplementary demand hours of each failure and labour activities. With choosing the appropriate clusters the coherence and the level of the coherences between product and procedures could be clearly seen.

To have an appropriate analysis it have to got an appropriate amount of data. In my case the analysis of a too-large number of product without the matching IT-support is an impediment to draw an adequate conclusion. Thus as the analysis's first step I picked up such product, which is suits to time-serial analysis and reflects to the given company's very production.

The Multi-Criteria Decision Aid (MCDA) has been one of the very fast growing areas of Operational Research (OR) during the two last decades. The MCDA often deals with ranking of many concrete alternatives from the best to the worst ones based on multiple conflicting criteria. In recent years, several MCDA methods have been proposed to help in selecting the best compromise alternatives [11].

The development of MCDA methods has been motivated not only by a variety of real-life problems requiring the consideration of multiple criteria, but also by practitioners' desire to propose enhanced decision-making techniques using recent advancements in mathematical optimization, scientific computing, and computer technology.

5. Results

There more than 200 types of products in the company's production assortment, with different distribution in time and in batch and serial sizes – mostly made by aluminium parts.

In the preliminary analysis there were 12 types of products being chosen, all of them were produced from 2002 to 2009, and all of the failure rates were available from the existing documentation.

The simplest way to make a calculation with correct results we should seem the failure part of the data in pieces or in per cent and the rework data as supplementary work hours.

These products are long-life series, especially for premium type cars, where there are no significant changes in the design of these elements for 5-7 years. There are several operations, labour activities related to these products, like cutting (cut to size), bending (draw-bending), cut-out, squeeze, milling, heat treatment, starching. The hypothesis was that the main problems are coming from bending – because the dynamic behaviour of these processes.

5.1. The disclosed failures

After the selection of the data we got 6 kinds of failures which could be measured and which encompass the entire process: Raw Material (RM), Surface (SU), Bending (BE), Labour (LA), Prototype (PR), Shipment (SH).

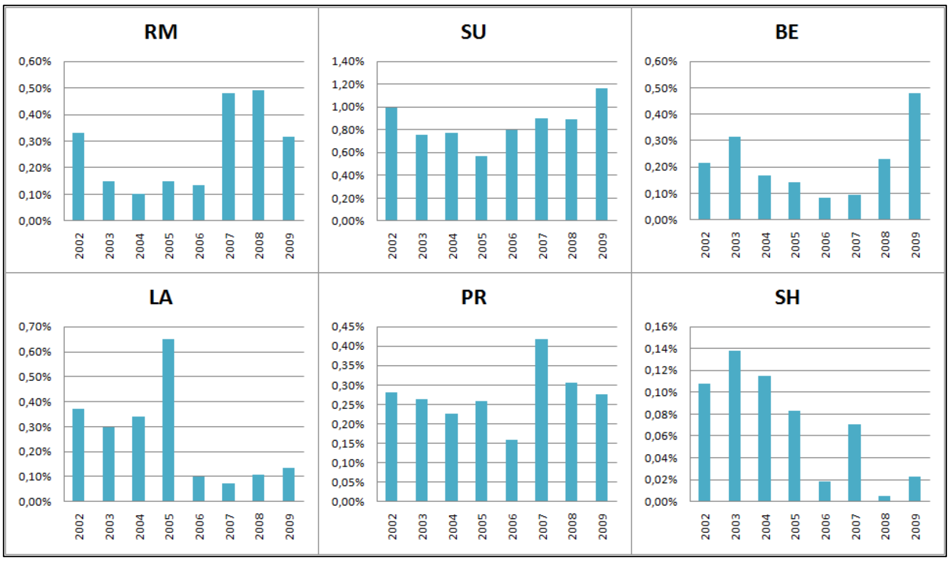

Figure 2. Failure trends (Source: Personal archive)

To have a more thorough analysis I have to note as following of the 2005 year the company fundamentally re-organized his raw material purchases. Previously it sourced through the parent company – the sent items recorded and registered and following of treatment it been sent back. Then the company switched over from the wage work-style production to the individual, fully accountable production.

By the year 2005 even the raw materials arrived to the company from various sources, and the control of the incoming items differed from those of previous periods. Obviously thus increased the occurrence of the raw-material-related faults. Yet – since instead of wage-work the appropriately reimbursed raw materials came from outside of the group of companies – the role of the quality control significantly increased. Hence the control of the very process became more transparent, obvious, traceable and identifiable. Same goes for the settings of the and equipments of the manufacturing and production: the increased independence required even more accuracy as well the removal of the possible faulty items still prior of the respective work-phases.

Prior of 2005, during the company's wage-work periods it was possible to sell the faulty raw materials as a waste (after the appropriate accounting procedure). Thus the company - by the available raw materials, with invoices, without countervalue - instead of a losses could make some revenues. If the parent company rejected to approve this practice, then the faulty raw materials been returned to the group of company's foundry.

The importance of the raw materials quality control as well the product-development related learning process clearly reflected on the failures of the Working. During the first years of the independent raw material management it been experienced the raw material-related problems, and they clearly separated from those of the working-related faults – hence these failures would be possible - or even became necessary - to identify, select and even eliminate during the raw materials quality control.

Year 2005 was a crisis for the company – there were plans about cutback, so in the results human errors could be included because of continuous imminence of being axed.

Hence the level of the interim confidence decreased, and the previously constant human productivity's satisfactory ratio significantly fallen down.

Surface problems started to increase after new product development in 2005 – premium category products need higher surface quality. Bending is critical since 2008, when a new machine was installed.

The other problem with bending is the physical impact on the aluminium piece – the inner structure of pieces are changing during the blending process, and the possible failures cannot be appear under the surface and heat treatment process at the company, just at the customer under further surface treatment work.

Numbers of prototype failures are coming from new product development.

Failures are coming from delivery and shipping arose following of the activation of new Suppliers. New products in the 2007 years required the alteration and correction of the delivery terms. These terms cannot be meet by the previous Supplier, thus by the 2008 it been added a new raw material Supplier to the production line.

5.2. Categoration of supplementary work

Supplementary work types were classified into 8 types: Prototype (PRO), Surface (SUR), Bending (BEN), Labour (LAB), Check (CHE), Packaging (PAC), Heat Treatment (HEA) and Other (OTH).

Related to years 2008 and 2009 the aggregate result shows that significant prototype-style supplementary work was requested (the reason is probably the high amount of new products, especially in 2008), and surface problems caused a lot of extra work again.

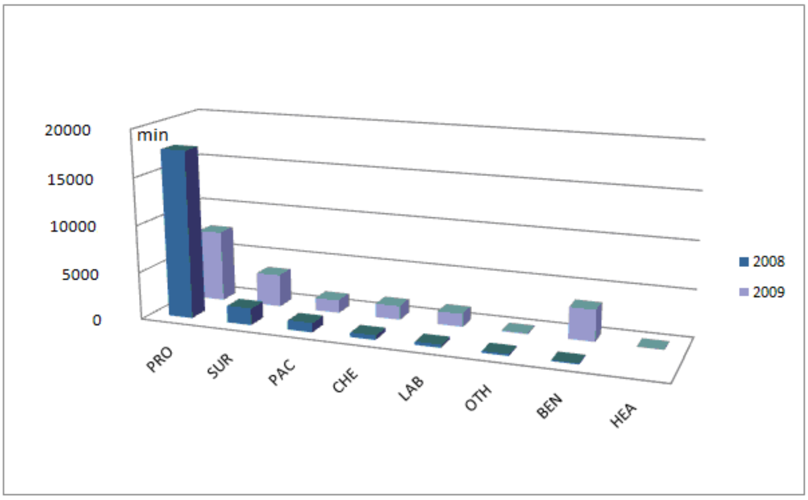

Figure 3. Supplementary work hour demand 2008-2009 (Source: Personal archive)

As long-life product, 108 520-21 L-R (0,072 kg / 310 mm) had been chosen for further analysis and comparison (bending – heat treatment – sawing – deflashing).

Figure 4. 108 520-21 L-R Product (Source: Personal archive)

The product manufactured in a left- and right hand version (L-R - according on which side of the bodywork will be installed. During the assessment of the failures, to disclose the possible failures of the two-side working's differences, it been compiled a faulty-mirror.

The failure mirror has the advantage to show clearly the processes and the failures with the left (links) and the right (rechts) version of the product.

0,00%	0,27%	0,92%	0,26%	0,00%	1,67%	2009	2,52%	0,00%	0,00%	0,97%	0,19%	0,00%
0,00%	0,27%	0,40%	0,00%	0,01%	3,28%	2008	6,43%	0,01%	0,08%	0,48%	0,38%	0,00%
0,00%	0,73%	0,28%	0,00%	0,01%	4,08%	2007	4,88%	0,01%	0,00%	0,41%	0,73%	0,00%
0,00%	0,46%	0,70%	0,03%	0,03%	3,94%	2006	5,11%	0,03%	0,16%	0,65%	0,41%	0,00%
0,00%	0,01%	0,51%	0,01%	0,12%	3,34%	2005	4,02%	0,13%	0,01%	0,62%	0,00%	0,00%
0,00%	0,88%	0,51%	0,05%	0,01%	7,12%	2004	8,37%	0,01%	0,00%	0,54%	1,03%	0,00%
0,00%	0,50%	0,39%	0,02%	0,00%	2,12%	2003	2,78%	0,00%	0,01%	0,38%	0,48%	0,00%
0,00%	0,85%	0,35%	0,08%	0,01%	8,05%	2002	4,65%	0,01%	0,09%	0,34%	0,61%	0,00%
SH	RM	PR	LA	BE	SU		SU	BE	LA	PR	RM	SH

Figure 5. Failure mirror of 108 520-21 L-R (Source: Personal archive)

It is interesting and surprising to see that there are not just similarities but also differences between left-right products, inspire of the fact that they were produced under the same circumstances. The differences are coming from different storage conditions of raw materials and machine settings problems.

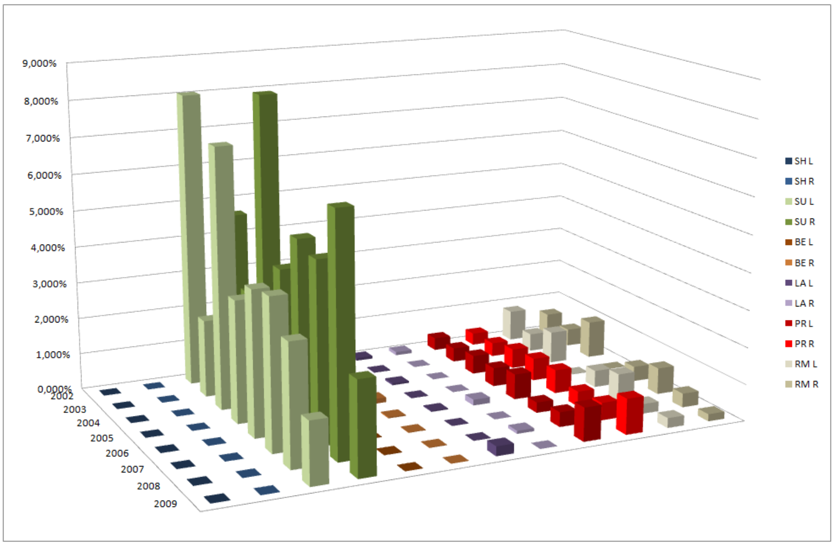

Figure 6. Failure trends of 108 520-21 L-R (Source: Personal archive)

In the background of surface failures the different origins and different storage conditions of raw materials appearing. Under long time storage of aluminium outside the structure of the metal is changing – but nothing can be seen from these changes before labour (bending, surface treatment).

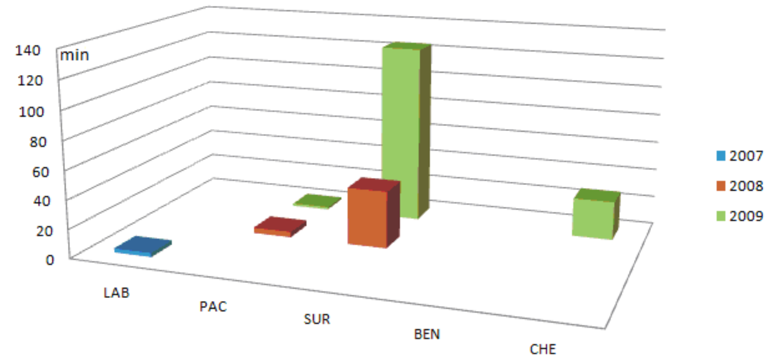

Figure 7. Supplementary work hour demand of 108 520-21 L

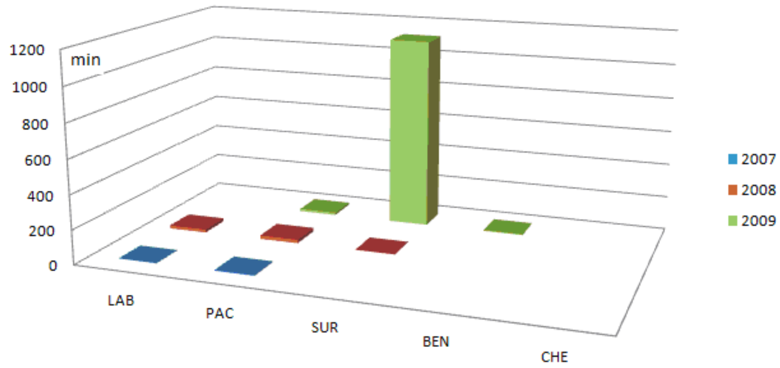

Figure 8. Supplementary work hour demand of 108 520-21 R

Significant differences are probably coming from different machine settings again (surface type supplementary work). The nature of surface errors is pretty much indecisive and capricious; a lot depend on visibility when inbuilt to the final place into the car.

5.3. The importance of supplementary work planning

Supplementary work hours have significant impact on the company performance.

It is crucial to get experience and forecast-ability for future series. From the past it could be seen that there are about five thousand pieces from small, and about hundred-thousand pieces from high serial batches for supplementary work.

The function of prototype-production is to get a sample with the best machine sets - this is significant at low batch series, because the products which made in low number of pieces are mostly expensive products (about 1-3% increase in the failure rate is not so significant, because in this case it is just a small amount of products – and even a large – percentage post-processing and working will not generate unbearable level of cost-increase).

The failures have multi-dimensional causes: batch size, labour time, number of processes, number of labour stations, lead times, etc. Classification of LP (low number of pieces, yearly 1-2.000), MP (medium number of pieces), HP (high number of pieces, yearly more than 100.000) series can help to estimate the cost of prospected supplementary work.

Based on multi-dimensional clusters the managers can be able to forecast the failure rates and supplementary work hour demands in the planning phase, and determine the possible bottleneck points in the production and in supplementary work.

Appropriate BSC measurements requests - according to the real nature of failures and supplementary works - for the development and optimization of the current processes.

6. Conclusions

Having an appropriate prediction of the supplementary work hour demand requires several factors from the operational logistics background, according to the experiences from the past – failure analysis (human and machine faults) and trends (batch sizes and errors, faults). The result could be a multi-dimensional database with well-tailored clusters, we described with illustrative examples.

It is not possible to find relationship between failures and supplementary works without the process-based administration of supplementary work hours – the registration today is mainly product-based, so it is hard to collect the work hour demands related exactly to the different supplementary activities.

It will require more study to have an accurate assessment on the relation between the supplementary work demand and the batch sizes

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Development of AIM Method Planning of Inbound Material Handling Processes

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Abstract The study shows the detailed examination of the AIM tables, a tool that helps the logistics system planning phase by calculating the needed time for each material handling processes. The method needed a revision because the tables were made 50 years ago, and a lot of changes have been made by the technological development. The study shows some possible acts and further ideas to update and develop the method to help the system planner better.

Keywords: material flow, time necessity, AIM tables, planning

1. Introduction

When we are talking about transporting a good from one place to another, most of the people think about freight forwarding on road, railway, water or in air. Those are also important parts of a good supply chain, no doubt about it. However there are the inbound material handling processes as well which connect the outbound forwarding to each other, and without these integral processes in a loading bay of a factory, or in a warehouse the whole chain would not work at all.

The participants of the supply chain want to achieve maximal forwarding volume, maximal customer satisfaction while they want to keep the costs of investment on minimum level in order to have higher income and profit. For achieving this goal you have to keep your supplying time on a low level, minimize the operational costs, so use the extant infrastructure and machines with the best efficiency. This is not easy to reach because there is a conflict between these goals. To reach high customer satisfaction you need to deliver fast so you do not have time to wait for other goods to fill up the truck for example. So the delivery volume is getting lower, efficiency of transportation is also getting lower so the operational costs are getting higher. This was an example of an outbound process but it has effect on the inbound processes as well.

These requirements of the market and the technical development have a huge effect on freight moving processes. The engineers have to take lot of efforts on planning and building a system that meets these requirements, that operates fast and on low costs (as possible) so shortly: optimally. They have to plan the number of machines, their consistence and distribution to create a good-working system with a low failure percentage. Besides the planning you have to maintain and control the working processes, control the operational efficiencies of the machines and recalculate the allocation of your resources if it is needed. For this job we need to have some tools, methods that bring correct information about our system in order to help us in the decision making process [2] [4].

The primary aim of this study is that to find the answer to the following question. How can we get time values about a process for the system planning? There are several methods to produce these numbers. I will concentrate on the tabular time defining methods which I will analyze in the views of usability, advantages and handicaps. I will shortly introduce a Hungarian method (AIM) and the final aim is that how can we build a better, more useful method (software) based on the former one, to help the planning and decision making process better.

2. Planning Methods

There are different ways to define the time necessity of weight moving processes during the planning phase. We can group those regarding precision and usability as follows:

1. Subjective guessing: Its advantage is quickness, we can produce the required data easily and in a short time. Disadvantages are that it has high chance that information is incorrect and a lot of experience is needed from the system planner to produce correct time information.
2. The data can be calculated from the technical parameters of the used weight moving machine(s) and from the parameters of the calculated process. If we use this method the advantage is that our values will be quite correct, but it takes a lot of time to calculate each details of the whole process and to define the restrictive parameters of the process, measure them, make usable numbers of them, use corrections if needed. For this last one it is very important that the planner has to have a lot of experience, because it is up to his/her professional routine.
3. Another way if we measure an existing system for time values. At first we need to have a similar system that is working and if we have that, we have to measure a lot to make a correct result with statistical analysis. Before using this value we have to verify the result whether it is relevant in the new planned system or not. Are there same circumstances (infrastructure, lay-out, machines…) or not.
4. Using data tables. We can say that here we mix the advantages of calculating and measuring methods, because every complex process can be cut into elements and these are equal regarding the time necessity. Two processes are different because they consist of different elements or they consist of the same

parts but their sequence or parameters are different. If we collect the time necessity of these elements in tables – using and regarding them as a time norm – we arrive to a tabular time planning method. Using these tables and building up the whole process with these norm elements we can get a rather correct time necessity for the process and in a relatively short time [2] [5] [8].

There are more existing table methods with time values which are available to use during the planning of weight moving and procedures and production planning. The planning has more than one level regarding the decomposition of the processes. The whole process consists of part-processes, in those there are activities, the activities consist of operations and finally motions or movements. Before planning we have to decide on which level do we stop our examination.

With MTM (Methods Time Measurement) we can calculate our procedure on the level of motions, so it has a very precise result but it takes time when we examine every single motion. These tables consist of the time necessity of defined technological operations based on a large number of elementary motions, and the time necessity of the elements as well. These motions are hand, body and eye motions (around 400) and we can build up the required operations, activities and finally our process. There is a Hungarian method – which is quite similar to MTM – called 3M that can be used for motion and work analysis and work planning [7].

The time tables can be used not only for motions but for operations as well. There are some methods based on the operational level of the processes, for example SMA and SMB. Those are the product of the French Material Handling Institution [7]. There is a Hungarian method also for planning material handling called AIM tables which I will introduce in this case study as a tool for decision making.

3. The AIM

The AIM tables were born at the middle of 1960s. Teachers and professors of the Department of Transport Technology in Budapest University of Technology and Economics translated the French SMB method into Hungarian and they gave the name AIM (a mosaic word in Hungarian: **A**nyagmozgatás **I**dőszükségletének **M**eghatározása – literal translation: Definition of Material Handling Time Necessities) to the Hungarian version. They did not add any new additional part for the method and they used the values of the French one. After creating they implemented that in the education and till then it is a part of the education of logistics engineers. Since then other institutions have implemented the method in their schedule and it has been used out of the walls of universities in the practical life too. However nowadays they hardly use it because of it's drawbacks.

The method can be used for calculating the time necessity of periodical operating material handling systems (i.e. forklift trucks, handling goods by hand or other intermittent-duty systems). When we have to define the time necessity of a continuous systems (i.e. conveyor, elevator…), it is easier to calculate with the technical parameters of the machine.

The aim of the AIM:

- to define the time necessity of a weight forwarding process
- to define how many machines, tools, workers the system needs
- to plan the schedule for tasks
- to analyze the working efficiency of existing systems

This method allows planning systems with the following material handling types:

- material handling by hand without any tools
- material handling by hand with tools
    a. hand pallet trucks
    b. handcarts
- electronic pedestrian stackers
- fork lift trucks
    - electronic
    - with internal combustion engine
- handling with towing tractor + roll cages [5] [6].

Table 1. AIM table for material handling by hand without any tools [6]

Material handling by hand without any tools						
H – Movement						
Sign		Weight (kg)	Time necessity (10^{-2} min/m)			
H -..- I		<2	1,1			
H -..- II		2..5	1,4			
H -..- III		5..20	1,7			
H -..- IV		20..50	2			
F – Taking the weight						
		Time necessity (10^{-2} min/m)				
Weight (kg)		0..10	10..20	20..30	30..40	40..50
High (m)	Sign	I	II	III	IV	V
0..0,7	1	8	10	11	15	16
0,7..1,4	2	6	8	10	13	14
1,4..2,1	3	10	12	13	15	17
L – Unloading the weight						
		Time necessity (10^{-2} min/m)				
Weight (kg)		0..10	10..20	20..30	30..40	40..50
High (m)	Sign	I	II	III	IV	V
0..0,7	1	6	7	8	11	12
0,7..1,4	2	4	6	8	9	11
1,4..2,1	3	8	9	10	11	12

Table 2. AIM table for material handling by hand with tools [6]

Material handling by hand with tools			
HKK – Movement			
Sign	Weight (kg)	Time necessity (10^{-2} min/m)	
		Pulling	Pushing
HKK -..- I	< 100	1,2	1,4
HKK -..- II	100..250	1,4	1,7
HKK -..- III	250..500	1,7	2,2
HKK -..- IV	500..1000	2,4	3,0
I – Start and stop			
Sign	Weight (kg)	Time necessity (10^{-2} min/m)	
		Pulling	Pushing
IM – I	< 100	6,0	3,5
IM – II	100..250	7,0	5,5
IM – III	250..500	9,0	7,0
IM - IV	500..1000	11,0	9,0
Loading with low elevating fork-lift			
F – Loading		**L – Unloading**	
Time necessity (10^{-2} min/m)		Time necessity (10^{-2} min/m)	
30		25	

3.1. Using of AIM

At first we have to disintegrate the whole process to elements. (Figure 1.) When we are ready with that then we can calculate each element's time. It is necessary to know that the values in the AIM tables are valid if the planned system is ideal. When the processes are not disturbed by any problems, the workers are well educated and not tired, the infrastructure of the firm (good light, flat floor…) is perfect. In this case we can calculate the time necessity of any activity and the result will be the so called *basic time* (t_1). We can use a table (Table 3.) for the values of each operation in which we can also include the multiplications, the frequency (f_i) of them. The final summary of the numbers will be the basic time of the activity. Of course the real systems are never ideal. That is why the method uses corrections for this basic time. There are correction values for the workers tiredness (p), and for the environmental factors (level of light, the gradient of the floor, the bottlenecks…) (k). If we add these corrections to the basic time (1), finally we get the *planned time* (t_2). This value is valid for real systems. If we have the productive time norm of one shift and the required amount of goods – which we move in the operation – we can easily calculate how many workers or machines can solve that task on time (2) [1].

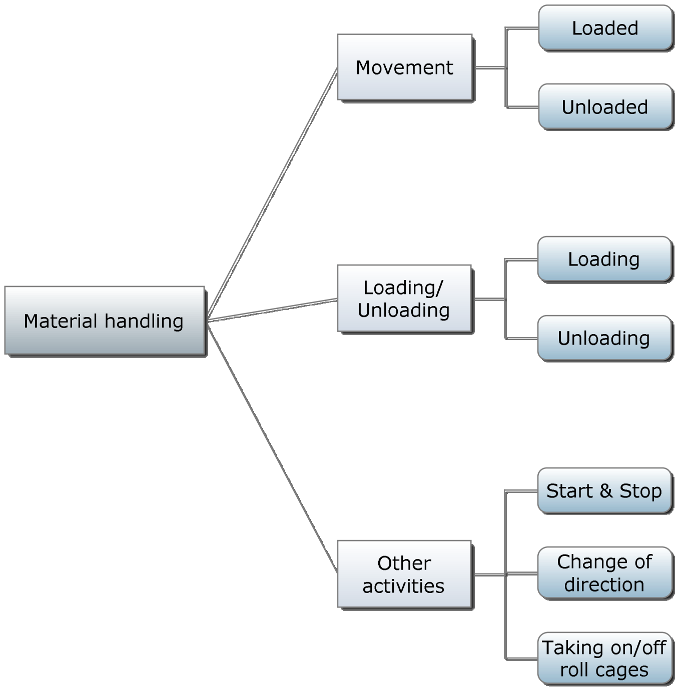

Figure 1. Disintegration of the process [authors]

Example:

The task is to load 20 pallets per shift with goods. On each pallet there have to be 195 pieces of goods. The productive time in one shift is 6.5 hours (the whole shift is 8 hours). The distance between the pallets and the goods is 1.5 meters. Both the goods and the pallets are on the floor. How many workers do we need to solve the task in one shift? [1].

Table 3. Calculating with values of AIM tables [authors]

Loading a pallet with hand power					
Nr.	*Name of the activity*	*Sign of the activity*	t_i [10^{-2}min]	f_i [piece]	$f_i \bullet t_i$ [10^{-2}min]
1	Taking the good	F-1-I	8	195	1560
2	Moving loaded	H-1,5-III	2,55	195	497,25
3	Taking down the good	L-1-I	6	195	1170
4	Moving unloaded	H-1,5-I	1,65	195	321,75
				$t_1 = \Sigma f_i \cdot t_i$	3549

$$t_2 = t_1(1 + p + k) = 35{,}49(1 + 0{,}1 + 0{,}05) = 40{,}81 \qquad (1)$$

$$N = \frac{n_{ER} \cdot t_2}{T_p} = \frac{20 \cdot 40{,}81}{6{,}5 \cdot 60} = 2{,}194 \qquad (2)$$

→ 3 people needed

3.2. Short SWOT analysis

3.2.1. Strengths

It is easy and fast to use the method. Everybody can learn how to use it quickly. The tables are well structured and transparent. There are several different handling machines and tools so more type of processes can be planned with the method. The activities are well divided, it is easy to build up a process with them.

3.2.2. Weakness, Threats

I will sum up the weaknesses and treads together, because the threads are the effects of weaknesses if we use the method.

The time values were defined in the ‘60s. Since then the technology has developed and the values might be incorrect which means the results of calculation with the method now may be not relevant. There were new machines announced since that time and these of course these are not involved in the method (such as order pickers, narrow aisle truck, rotatable forked truck…). The lifting height is also higher than it is in the tables.

The speed of the travelling depends on the load’s stability and this correction parameter is not involved into the calculations. The less stable load needs slower travelling speed specially in curves.

There are no administration times included in the tables. It also makes the result incorrect. In these processes it is necessary to identify the right places where from and where to move and identify the material to move the right one. These take a lot of time, we can not forget about it during the planning.

The existing form of the method is paper. There is no electronic form. Nowadays everybody use computers, so am I. When I used the method I used MS Excel for calculations. It means that I handled the computer and a paper tables in the same time. It made the work harder.

The method is only used in the education, I have never met a company which would use it. It is understandable if we look at these weaknesses. We can not use the method universally, the planning is limited and if we could use it, we can not be sure that the result is relevant. The thread is that if we are not aware of these.

3.2.3. Opportunities

The method has to be thought over again. After a detailed measurement the former tables have to be updated with new values, new machines and correction parameters involved. It should be a software, based on computer, to help the planners work [1].

4. The method to develop

4.1. Goals

The aim of the method is still the same: define the needed time for inbound handling processes, thus supporting the encountered decision making situations during planning. The time values should be produced quickly, easily and as accurately as possible with a computer application. To achieve this, a transparent, easy to use operator interface should be developed. The results of the calculation need to be shown on a graphical screen with simple feedback to the former data for modification if needed. In order to make the documentation and archiving easier the possibility of saving and printing results on automatically filled sheets must be created.

4.2. Calculation methods, giving parameters

The current time constants in the AIM tables are for calculating basic time[1]. From the basic time we calculated the real values using some modifying factors of environment, working circumstances. Later we can understand that in the new method we do not need to use these factors because the speed of the computer's calculation enables to import the factors into the core calculation (connected to each part of the path) and this way we have to handle the final results as correct ones. When it comes to defining the time

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[1] The basic time is needed for a usually trained and relaxed worker to do the task with ideal circumstances

constants and parameters we need to be careful. After detailed, comprehensive sets of measurements the results must be compared with the existing ones in the tables. If there is no difference we can use the former values in the application. We have to decide of each value or parameter if it is universal or individual – related to a specified process or machine. For example when we talk about the applied speed of forklifts we have to know if the data depends on each manufacturer's product or can be used for any machine in the same category. Now in the tables only the electronic and internal combustion engine powered forklifts, low elevating power forklifts and electronic forwarding trolleys are represented. Of course at the end of the measurement the data comparison can be done only with these types of material handling machines. As there is a need to involve other machines in the method, so measuring those others is essential as well. These can be the reach truck – which is very popular nowadays -, rotatable forked truck, narrow aisle truck, picking truck.

There is an other question which has to be answered, that is there any connection with the measured data and the physical parameters of the machines? If it exists the machine specific calculation is available. That means when using the program, the user only has to choose a machine from a list and the software will calculate with the parameters of the catalogue of that truck such as speed, acceleration, braking time… This way there can be differences between the results of the same task using different brands of trucks. If there is not close connection of the two data, the measures of different types have to be examined for any possible aggregation or concentration of data. As a result we can use the same value for a group of same type trucks (of course if it is relevant). It is emphasized that the used values have to be relevant with the real world (not for ideal environment and workers), with the effects of OSH (Occupational Safety and Health) regulations included. The aim is that there have to be relevant and representative values in the database of the method for correct and usable results.

The parameters of the software have to be divided in two groups. One type is the parameters related to each type of machines – universally used for the same type of machines – and the machine-specific parameters, which are different for every each machine. So in the future during using the software the user has to choose a machine that he/she wants to operate for the task and the program will calculate with the machine's parameter list which contains machine-specific and type-specific parameters – so called group parameters – as well. To define these, the planner has to be attentive. Every parameter has to be planned whether it is group or individual value. This will be an outcome of the future measures, only after that can the values be divided.

We have to remember, that the AIM tables contain not only machines, but handling processes without equipment and other processes using pull trucks, stackers or pedestrian pallet trucks (based on pedestrian work force). In this case I do not advise modification, because the human parameters (such as walking and weight lifting speed) has not changed during this 50 years, but to be sure I would suggest to do some measurement in these cases too to verify my statement. According to this I would install these values into the new application without any changes, so in the following rows I do not want to mention these processes [1].

4.3. The usage of the system

When the application is used for planning any system at the first step the whole process has to be divided into well separated groups (such as receiving, shipping, taking to storage space, order picking), just like we did in the old method. After this phase the planner continues the planning of the separated processes one-by-one. The next step is to define different tasks in these processes (for example loading the pull truck by hand, travelling loaded/unloaded, building unit load…). The planning is continued by specifying needed parameters for each task. The used machine has to be chosen, the task has to be linked to the previous one (to build up the order of tasks and let the computer work with the tasks as parts of a process). Within the tasks the user has to choose activities to build up the task (choosing from a list). These activities can be walking, taking weight up/down, travelling, loading/unloading… The parameters must be given to each activity, such as travelling distance, number of curves (90° curves to make the planning easier), number and scale of bottlenecks, length and scale of slopes. The program offers for filling in only those parameters that are related to the chosen activity. If we finish giving the parameters for a task we can go on to the next one until we fill in all the needed data for the process. With this step this phase of the planning is done.

Table 4. Phases of planning [1]

Process	Task 1	Activity 1
		Activity 2
		Activity n
	Task 2	Activity 1
		Activity 2
		Activity m
	Task k	

Example:

Table 5. Phases of planning – example [1]

Shipment (receiving area – storage area)	Loaded phase (using pedestrian pallet truck)	Loading
		Walking with pallet
		Unloading
	Unloaded phase	Walking without pallet

In the next phase the program does the calculations and shows the result for every task, asks about the number of cycles (depending on the handled amount of material). If we do not know this value, we can make the application calculate this by giving the number of pallets, or total amount of materials and handled weight in one cycle. With these data it can produce the total needed time for the process. In the next step we can give the productive time of the shift (~6.5 hours of an 8-hour shift), so the application can define the needed number of machines or workers. There will be a graphical screen of the result, showing the process with Gantt diagram. With this screen the user can plan parallel tasks easier (more tasks in the same time) and modify the result by dragging and dropping each task by mouse, if the offered result is not good enough for the allocation of resources. At the end there will be possibility to print or save the results for late documentation or replanning.

For an example of planning parallel tasks take a look at the system on figure 2. In this example the building of unit loads by hand is a continuous process. We use tow tractors to move the pallets to an other location. Each tractor can bring 4 pallets. Without good planning it can happen that the tractor has to wait for the building of these 4 pallets and it can bring them only if they are ready. To avoid this waiting and establish a continuous work we need to plan these parallel activities. With the former method we could only plan serial (not parallel) tasks and after it was up to the planner to build parallel system from the serial processes. By using Gantt diagrams in the application, the possibility to plan that is given.

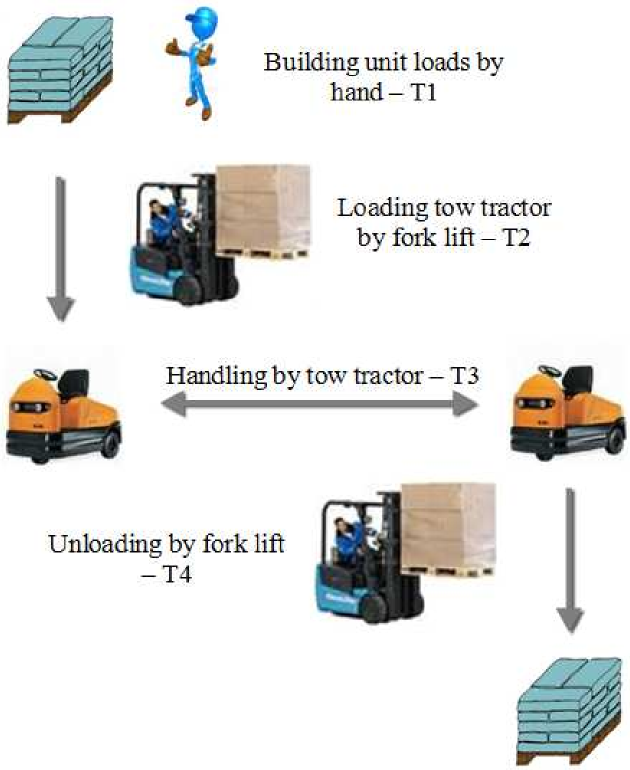

Figure 2. Example: parallel tasks

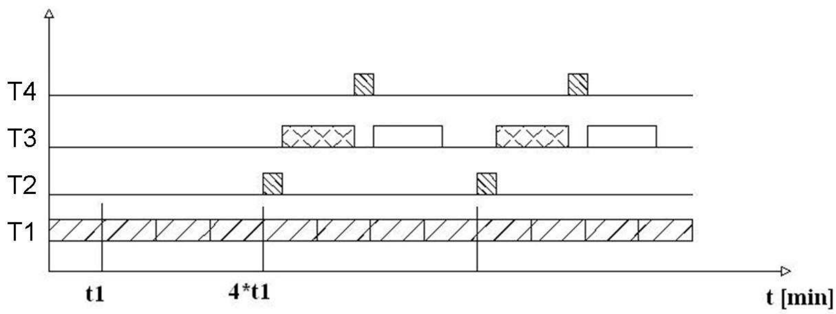

Figure 3. Example: Gantt diagram of parallel processes

If there would be some other processes near the two locations and the user would include the Gantt diagrams of those, he/she could plan them together. We can see that the two forklifts in the two places are not used enough, so we can give them other tasks meanwhile they wait for the tow tractor.

For better transparency by clicking on any task on the diagram a small window will show the detailed activities of the task with time values. As I mentioned before, it is also possible to modify the order of tasks by hand (of course where it is allowed).

This new application – that I detailed above – would meant to help the complex planning process in the future. My aim is to develop such software that is not only used in the education but becomes useful in the practical life as well [1].

5. Conclusion

During the planning of inbound material handling processes it is essential to define the duration of each task. If we know these values it is possible to define the details of the process and the number of needed resources (machines, workforce). We have a tool to help this planning, it is called AIM method. This is based on tables that contain time values which are used for building up a complex process. The method was born in the middle of '60s, as a translation of the French SMB method.

I examined the advantages of it:

- well structured
- easy to learn the usage
- simple
- transparent.

Based on these attributes it represents a good support for planning when approximate result is acceptable.

The tables have several disadvantages too:

- the contained values might be incorrect
- there are a lot of missing machines (since the technology has been developing since the '60s)
- not electronic
- approximate way of calculation
- lot of missing influencing parameters (load stability, administration times)

Based on these disadvantages I examined the expectations for a future application to be developed. My requirements for this program to produce more correct time values and required resources for the tasks by more detailed way of calculation, more influencing parameters (load stability, detailed path calculation).

By this reconsideration of the method I want to create software, so based on the quickness of the computer these detailed calculations can be done. The user will be able to plan more complex systems, faster than before, the result will be more correct, and there will be more machines available to involve the planning. We will have a simple, easy-to-use application avoiding the disadvantages of the former method. The final aim is that thanking to trustable software not only the universities will use that for education but also companies will gain benefit from this.

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The Railway Infrastructure Service Qualification System Model

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Abstract The paper demonstrates a possible solution for determining a railway infrastructure service and connecting charging system which adapts to market needs (creating conformity between supply and demand). The developed "networkmatrix" structure model is able to unified store and treat all feature datas of railway station and line in exact mathematic way, by unambiguously identifying the matrix components. The paper covers the methodology of determining commercial value of railway infrastructure services and service qualification system model – developed with the help of genetic algorithm – which harmonises the EU directives, and can be used in Hungary and in international networks as well.

Keyword: railway infrastructure services, qualification model, genetic algorithm

1. Introduction

Council Directive 91/440/EEC on the development of the Community's railways and Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification created the new regulation of the European transport market through opening the market for international freight and services [8] [9].

The railway enterprise restructuring dividing infrastructure operation and transportation functions raises the issue of the service system provided by the infrastructure manager and the connecting charging system. All members of the EEC[1] try to reform the operation of their incumbent railway systems through creating transparent market relations, settling the role of states in ordering public utility services, taking measures in order to develop competitiveness and making service contracts between demand and supply [1] [4].

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[1] European Economic Community

The topic of the paper is relevant especially as there are not any harmonised, standardised and accepted infrastrutcure service systems existing while developing and using such a system is indispensable according to legal regulations and the economical interest of the market members.

The subject of the paper is topical as in the current situation of the domestic railway enterprise restructuring, when the basic task of Hungarian State Railways Co (MÁV) is operation and maintenance of the railway network and providing infrastructure services, it would be possible to develop and improve the service system on the basis of professionnal principles so thus making it able to adapt to changing market environment.

2. Scientific results

2.1. Networkmatrix

I developed the networkmatrix structure model which is able to unifiedly store and treat all station and line feature datas in exact mathematic way, by unambiguously identifying the matrix components.

Buildups of station and line feature name vectors are the followings:

$$\underline{Ta} = \begin{bmatrix} (ta)_1 \\ (ta)_2 \\ \vdots \\ (ta)_n \end{bmatrix}, \quad \underline{Tv} = \begin{bmatrix} (tv)_1 \\ (tv)_2 \\ \vdots \\ (tv)_o \end{bmatrix} \tag{1}$$

where $(ta)_i$ means the i-st feature name of stations,

n means the number of features in station feature name vector,

$(tv)_l$ means the l-st feature name of lines,

o means the number of features in line feature name vector.

In view of the content of station, respectively line feature name vector it is possible to determine station- respectively linevectors (A, respectively V), which contain the concrete station respectively line feature values for certain station respectively line according to Ta respectively Tv feature name vectors in the following form:

$$\underline{A}^a = \begin{bmatrix} (ta)^a{}_1 \\ (ta)^a{}_2 \\ \vdots \\ (ta)^a{}_n \end{bmatrix} \quad \underline{V}^{a,b} = \underline{V}^w = \begin{bmatrix} (tv)^{a,b}{}_1 \\ (tv)^{a,b}{}_2 \\ \vdots \\ (tv)^{a,b}{}_o \end{bmatrix} = \begin{bmatrix} (tv)^w{}_1 \\ (tv)^w{}_2 \\ \vdots \\ (tv)^w{}_o \end{bmatrix} \tag{2}$$

where *a* and *b* mean the name of station

$(ta)^a{}_i$ means the concrete quantitative, qualitative value of i-st feature name of stations on the station a,

$(tv)^w{}_l$ means the concrete quantitative, qualitative value of the l-st feature name of lines on the line w,

Va,b = Vw means the w linevector which illustrates the link between station a and station b and which contains o elements.

From station- and linevectors it is possible to build up a 3dimension networkmatrix (H), which contains all features of stations and lines fixed in station- and linevectors and the network topology for the whole network as well.

The elements of H networkmatrix are:

$$\underline{\underline{H}}^{a,b} = \begin{cases} \underline{A}^a, & in \quad the \quad case \quad of \quad a = b \\ \underline{V}^{a,b}, & in \quad the \quad case \quad of \quad a \neq b \end{cases} \tag{3}$$

where meanings are the same as above.

Accordingly, stationvectors are in the main diagonal and linevectors are in other part of the networkmatrix, in the case of a network with f pieces of stations would look like [2]:

$$\underline{\underline{H}} = \begin{bmatrix} \underline{H}^{1,1} & \underline{H}^{1,2} & \cdots & \underline{H}^{1,f} \\ \underline{H}^{2,1} & \underline{H}^{2,2} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \underline{H}^{f-1,f} \\ \underline{H}^{f,1} & \cdots & \underline{H}^{f,f-1} & \underline{H}^{f,f} \end{bmatrix} = \begin{bmatrix} \underline{A}^{1} & \underline{V}^{1,2} & \cdots & \underline{V}^{1,f} \\ \underline{V}^{2,1} & \underline{A}^{2} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \underline{V}^{f-1,f} \\ \underline{V}^{f,1} & \cdots & \underline{V}^{f,f-1} & \underline{A}^{f} \end{bmatrix} \tag{4}$$

Meanings are the same as earlier.

2.2. Conversion rule system

I developed the conversion rule system based on vector operations which is able to homogenise, quantificate heterogeneous station/line features, and with which help it is possible to make quantitative, standardised convertiated vectors from different heterogeneous station- and linevector data.

In order to treat heterogeneous station/line features uniformly on mathematic language, it is necessary to quantify textual station/line features, respectively to develop solutions for treating numeric features uniformly in order to compare different features. This is made by convertative vectors (Ka, respectively Kv) [2].

Convertiated vectors for a station and w line are the followings:

$$\underline{C}^a = \begin{bmatrix} c^a{}_1 \\ c^a{}_2 \\ \vdots \\ c^a{}_n \end{bmatrix} = \begin{bmatrix} (ka)_1\left[(ta)^a{}_1\right] \\ (ka)_2\left[(ta)^a{}_2\right] \\ \vdots \\ (ka)_n\left[(ta)^a{}_n\right] \end{bmatrix}, \quad \underline{C}^w = \begin{bmatrix} c^w{}_1 \\ c^w{}_2 \\ \vdots \\ c^w{}_o \end{bmatrix} = \begin{bmatrix} (kv)_1\left[(tv)^w{}_1\right] \\ (kv)_2\left[(tv)^w{}_2\right] \\ \vdots \\ (kv)_o\left[(tv)^w{}_o\right] \end{bmatrix} \tag{5}$$

where $c^a{}_i$ namely $(ka)_i\left[(ta)^a{}_i\right]$ means convertiated value got by adopting (ka)i convertative rule to station a station feature i,

$c^w{}_j$ namely $(kv)_j\left[(tv)^w{}_j\right]$ means convertiated value got by adopting (kv)j convertative rule to line w line feature j.

As the result of conversion, vectors of elements between 0 and 1 are generated. From heterogeneous station- respectively linevectors I prepared such homogenised vectors which have – in the case of discrete mapping almost the same, in the case of continual mapping the same – meaning, and have quantified quality as well.

2.3. Commercial value

With the help of networkmatrix structure model I developed the methodology of determining commercial value of services. With the help of this, it is possible to analyse and verificate the quality of services numerically, dynamically and informatically.

For determining quality from several infrastructure services point of view not all features are necessary so thus it is important to identify relevant features from the services point of view. After determining relevant features, station respectively line service weightvectors sort out relevant features by a mathematical model and quantificate features according to their role in commercial value.

Station respectively line service weightvectors are the followings:

$$(\underline{Sa})^{m_j} = \begin{bmatrix} (sa)^{m_j}{}_1 \\ (sa)^{m_j}{}_2 \\ \vdots \\ (sa)^{m_j}{}_n \end{bmatrix}, \quad (\underline{Sv})^{u_q} = \begin{bmatrix} (sv)^{u_q}{}_1 \\ (sv)^{u_q}{}_2 \\ \vdots \\ (sv)^{u_q}{}_o \end{bmatrix} \tag{6}$$

where $(sa)^{m_j}{}_i$ means the weight from mj service point of view which belongs to the i-st feature name of stations [(ta)i],

$(sa)^{m_j}{}_i$ means the weight from mj service point of view which belongs to the i-st feature name of stations [(ta)i],

$(sv)^{u_q}{}_l$ means the weight from uq service point of view which belongs to the l-st feature name of lines [(tv)l].

Elements of service weightvectors are between 0-1, they contain value differing from 0 only where convertation and convertiated vectors contains values for relevant features. Elements of service weightvectors means how important the station/line features are from service quality level point of view. The sum of elements of service weightvector gives 1.

Commercial value of station a from mj service point of view, respectively commercial values of line w from uq service point of view are the followings:

$$\mathrm{e}^{\mathrm{am_j}} = \mathrm{c^a}_1 \cdot (\mathrm{sa})^{\mathrm{m_j}}{}_1 + \mathrm{c^a}_2 \cdot (\mathrm{sa})^{\mathrm{m_j}}{}_2 + \cdots + \mathrm{c^a}_\mathrm{n} \cdot (\mathrm{sa})^{\mathrm{m_j}}{}_\mathrm{n} \tag{7}$$

$$e^{wu_q} = c^w{}_1 \cdot (sv)^{u_q}{}_1 + c^w{}_2 \cdot (sv)^{u_q}{}_2 + \cdots + c^w{}_o \cdot (sv)^{u_q}{}_o \tag{8}$$

Commercial value of a service can be between 0 and 1.

From commercial value of services it is possible to develop station respectively line commercial value vector, which contains the same number of elements as station- respectively line vector. From station respectively line commercial value vectors the three dimension commercial value matrix (E), can be built up, which contains the commercial values of all stations and lines from all services point of view:

$$\underline{\underline{E}} = \begin{cases} \underline{E}^a, & ha \quad a = b \\ \underline{E}^{a,b}, & ha \quad a \neq b \end{cases} \tag{9}$$

According to the above, in the diagonal of network commercial value matrix station commercial value vectors can be found, on other places line commercial value vectors as followings:

$$\underline{\underline{E}} = \begin{bmatrix} \underline{E}^{1,1} & \underline{E}^{1,2} & \cdots & \underline{E}^{1,f} \\ \underline{E}^{2,1} & \underline{E}^{2,2} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \underline{E}^{f-1,f} \\ \underline{E}^{f,1} & \cdots & \underline{E}^{f,f-1} & \underline{E}^{f,f} \end{bmatrix}. \tag{10}$$

Meanings are the same as earlier.

2.4. Common commercial value of infrastructure services

I developed the methodology of determining common commercial value of infrastructure services, which with the appropriate rate of commercial value of supply and demand ensures that charge according to quality (commercial value) can be determined.

I developed such a service qualification model, which suits railway undertakings' quality aspects and demands, reflects costs and expenditures of infrastructure manager, namely harmonises and treats the commercial value for both railway undertakings and infrastructure managers as the following:

$$e^{am_j vp} = x \cdot e^{am_j p} + (1 - x) \cdot e^{am_j v} \qquad (11)$$

where $e^{am_j vp}$ means common commercial value from mj service point of view,

$e^{am_j p}$ means commercial value of infrastructure managers from mj service point of view,

$e^{am_j v}$ means commercial value of railway undertakings from mj service point of view,

x means in what rate the infrastructure manager's commercial value is taken into account. The following coherency is always valid that $0 \le x \le 1$.

In the course of qualification and charging of services I determine the value of x with the help of genetic algorithm.

2.5. Service qualification system with genetic algorithm

With the help of genetic algorithm [7] I developed service qualification system model which harmonises the EU directives, and can be used in Hungary and in international networks as well. The model determines optimal common commercial value and charging system considering costs and expenditures of infrastructure managers and quality of service at the same time.

Figure 1 shows the process of qualification and charging with the help of genetic algorithm.

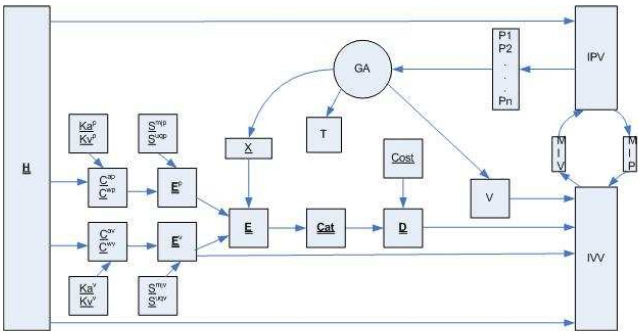

Figure 1. Model of determining common commercial value and charging with genetic algorithm [11]

Meanings are the same as earlier or are to be explained in the following description. After determining quality of service, station a from mj service point of view, respectively line w from service uq point of view can be categorised, from which' elements category vectors and lastly categorymatrix (Cat) can be developed.

Considering e.g. average cost of service categories of all station and line services, station respectively line costvectors can be made (Cost). The charge of service with given quality (category) can be determined with the help of average cost and categorymatrix according to different charging principles. From charges the chargematrix (D) can be built up.

The infrastructure manager (IPV) answers (MIP) claims (MIV) of railway undertakings (IVV) (which are determined due to different transportation tasks generated by genetic algorithm) depending on their achievability. The claim can either be fulfilled (after iteration between IPV and IVV if there are changing requirements) or refused. The results of transportation are compared with the parameters determined in goodness criterias and measured in data puffers. Among goodness criterias other criterias that are in line with the requirements of the market members can be determined (like optimal capacity utilisation from infrastructure manager's point of view, payback of a certain level of cost of infrastructure manager from the state's point of view, minimalisation of full costs of a claim from railway undertaking's point of view). All results are saved in spooler (T). Genetic algorithm prepares x parameter of service qualification system according to goodness criterias, till the ideal qualification (proper rate of respect of $e^{am_j p}$ and $e^{am_j v}$, respectively $e^{wu_q p}$ and $e^{wu_q v}$) and charging is determined and parameters described as goodness criterias are best fulfilled [11].

3. Conclusions

With the help of the developed networkmatrix structure model it is possible to determine commercial value, based on station/line quality level, of all station and line on the network of any infrastructure manager, what can form the basis of any cost and income calculation. Based on commercial value it is possible to determine categories of stations/lines and the charge for their usage. The principles above can be used in practice as well if all stations and lines are categorised by the method described by the infrastructure manager.

The optimal charging system [10] can be developed with the domestic usage of service qualification system, taking into consideration the infrastructure costs and expenditures connected to services and the quality of the service. The method is possible to be used in practice in countries with similar endowments and specialities, furthermore after implementation in countries with different endowments and specialities, too.

Through collecting and arranging all features necessary for determining station/line categories the model gives the possibility to prepare a uniform database, in which any changes of any characteristics of any services can be seen across or modified. This kind of database that contains all standard attributes of stations and/or lines has not existed. Such a database can be the starting point of introduction, differentiation, categorisation and determination the charge of further services.

During the practical adaptation of the model it is possible to measure the frequency of usage of stations/lines with different categories, to measure which station/lines with which services are the most wanted ones [9]. This helps to identify stations/lines which are necessary to be developed or derogated – depending on the construction of the network – from given service point of view.

With the help of the model there is enough information about overloaded stations/lines (bottlenecks), as well as "weak points" of the infrastructure thus supporting the substantiation of correct infrastructure strategy and policy decisions. The model makes possible to quantify how service level, quality and charge of service provided by domestic infrastructure managers' approach to the demand for services. This can be the basis of a competitive offer.

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Development of Railway Infrastructure Services and Customer Satisfaction

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Abstract The paper presents the implementation and further development possibilities of the Hungarian railway infrastructure service system focusing on its support with informatics applications. The presentation also introduces the methodology and main related results of customer satisfaction research of MÁV IBU.

Keywords: railway infrastructure services, customer satisfaction

1. The actors and the performance of the liberalized transport market

1.1. The main characteristics of the Hungarian railway market

Hungary joined to the European Union on 1st May 2004 and it brought significant changes to the Hungarian railway market. As the result of the rail freight market liberalisation different rail freight operators appeared on the open-access railway network beside the previous two former market actors, MÁV Co. and GySEV Co.

The passenger market liberalization began in 2010, now three railway undertakings (RUs) have valid operation licence for passenger transport. Two of them provide public transport service and one operator is specialized in transport of nostalgic trains. The first foreign contract partner was a Slovakian train operator whom MÁV Co. concluded the network access contract in 2008 with. Since then further Slovakian and Austrian railway undertakings decided to enter to the Hungarian railway market, some of them have already concluded network access contract. The trend is similar to other European countries: the number of customers increases, however, the market share is prevailed by the national railway company [1].

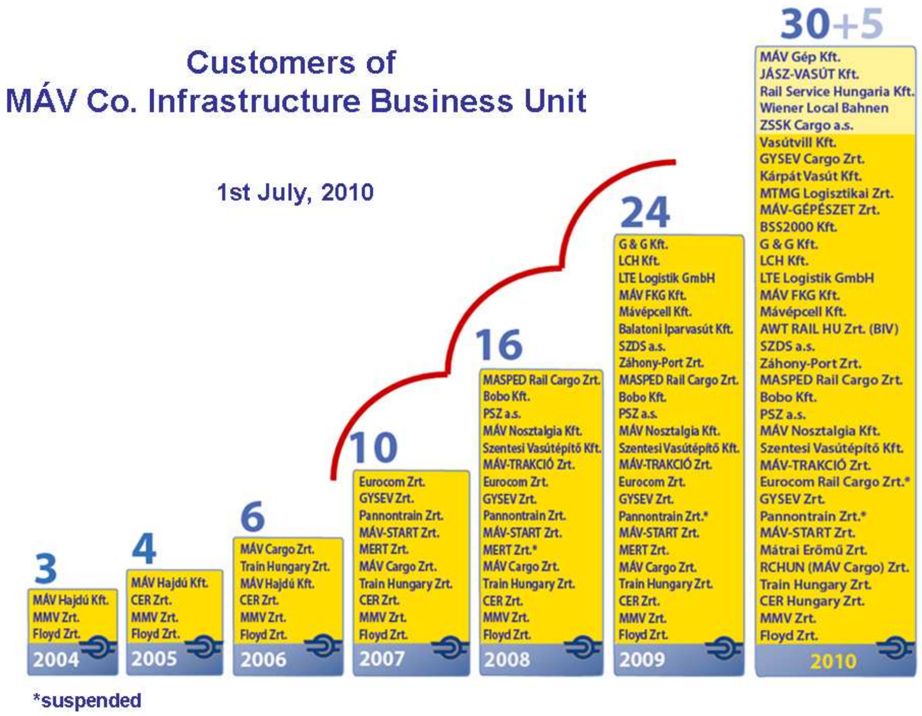

Figure 1. The development of the number of the railway undertakings having network access contract (Source: MÁV Co. IBU Sales Department)

The rail operation is quite complex, so that the network access conditions are much stricter than in the road transport. The number of the railway undertakings on the Hungarian railway network is not expected to reach the German one (300), but the dynamic growth will stop after a while. Based on the granted operation licences is expected that 8-10 further railway undertakings comply with the legal requirement, and become eligible to access in 2010. Probably, more and more foreign companies will be interested, who already have operational licence in other EEA member states. This is more likely after the liberalisation of the railway passenger market.

1.2. Trends of the performance

The success of the market liberalization is characterized mostly by the competition between the operators, the steps and speed of the passenger transport market's allocation and the whole market transport volume counted from the share of the individual market players [10].

The characteristics of the MÁV Co's railway infrastructure and the number, as well as the performance of the run train on the railway network are shown in the Table 1.

Table 1. The characteristics of the MÁV Co's railway infrastructure and performance (Source: MÁV Co. IBU Brochure [6])

	2004	2005	2006	2007	2008	2009
Built length of railway network (km)	7 650	7 650	7 650	7 596	7 511	7 511
Built length of double track railway lines (km)	1 146	1 146	1 146	1 173	1 173	1 173
Rate of double track railway lines (%)	14,98	14,98	14,98	15,44	15,62	15,62
Rate of electrified railway lines (%)	33,55	33,55	33,55	33,79	34,17	34,17
Run freight train (pieces)	212 827	216 405	237 497	221 976	195 644	137 510
Run passenger train (pieces)	1 112 448	1 020 344	1 044 186	1 078 066	1 076 229	1 085 043
Kilometres by freight trains	16 498 213	16 954 000	18 963 648	18 836 132	18 276 716	14 278 253
Kilometres by passenger trains	80 237 372	75 396 595	77 238 250	84 527 403	83 447 780	84 128 416
Punctuality of passenger trains (%)	94,78	94,14	92,89	93,39	92,6	90,8
Staff	19 918	17 878	18 565	17 575	17 272	17 102

The rail freight transport performance on the Hungarian open access railway network between 2004 and 2009 decreased by approximately 15%. This is mainly caused by the impact of the general economic downturn begun in 2008.

In general the market opening alone did not cause the expansion of the Hungarian rail freight market, but it is difficult to judge how the total market volume would have changed in case of the failure of market opening and lack of the number of efficiency measures [2].

The Hungarian freight transport performance on the basis of data collected by Hungrail is shown by Figure 2.

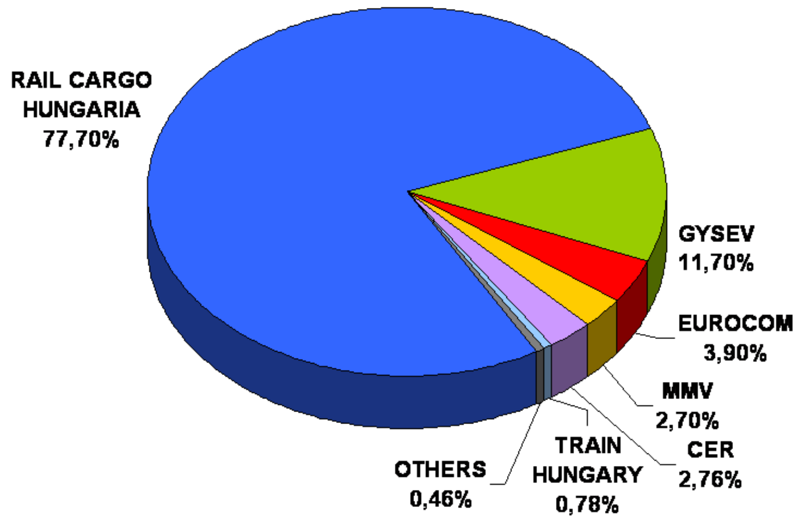

Figure 2. The share of the Hungarian rail freight transport performance (2009)
(Source: Hungrail Annual Report 2009, Hungarian Rail Association [3])

As it can be seen from the figure Rail Cargo Hungaria Co. (RCHUN) still retaines the greatest market share. In 2009 a determining circumstance for that company was the fact that its resources and capabilities were combined with parent company Rail Cargo Austria. The second major player is still GySEV Co. which, similar to RCHUN (former MÁV Cargo Co.), suffered a 25% drop in the last year. The decrease was primarily a result of the economic recession the effect of which was felt intensely in the reduction of freight demand from the automotive industry [3].

The standard of rail infrastructure in Hungary and the efficiency of the services are significantly lower than some neighbouring countries of the European Union. In spite of that fact the track access charges are extremely high compared to other – especially western part of European – countries and this is in great part responsible for the fact that freight is often taken by road instead of by rail.

Usage-based road pricing partially introduced in the European Union in 2009 has not significantly altered road-rail competition in the freight market. The aggressive policy of road competition combined with the demonstrable advantage of the delivery of goods from door to door continues to result the reduction of European rail freight transportation [4].

1.3. The development and the main features of the railway market liberalization

The liberalization of the national railway market has created and still provided the following regulatory environment as its framework [7]:

- 91/440/EEA (and its amendments) on the development of the Community's railways. The directive has defined the development of the community's railways in four main points:
    - Ensuring of the independence of the state.
    - Arrangement of the financial situation.
    - Unbundling of the trading and infrastructure activities.
    - Ensuring open access for the new entrant third parties.
- 95/18/EC directive (and its amendments) on the licensing of railway undertakings
- 2001/14/EC (and its amendments) on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification.
- 62/2006/EC directive on concerning the technical specification for interoperability relating to the telematic applications for freight subsystem of the trans-European conventional rail system.
- 2005. CLXXXIII. Act on the railway transport (Vtv.)
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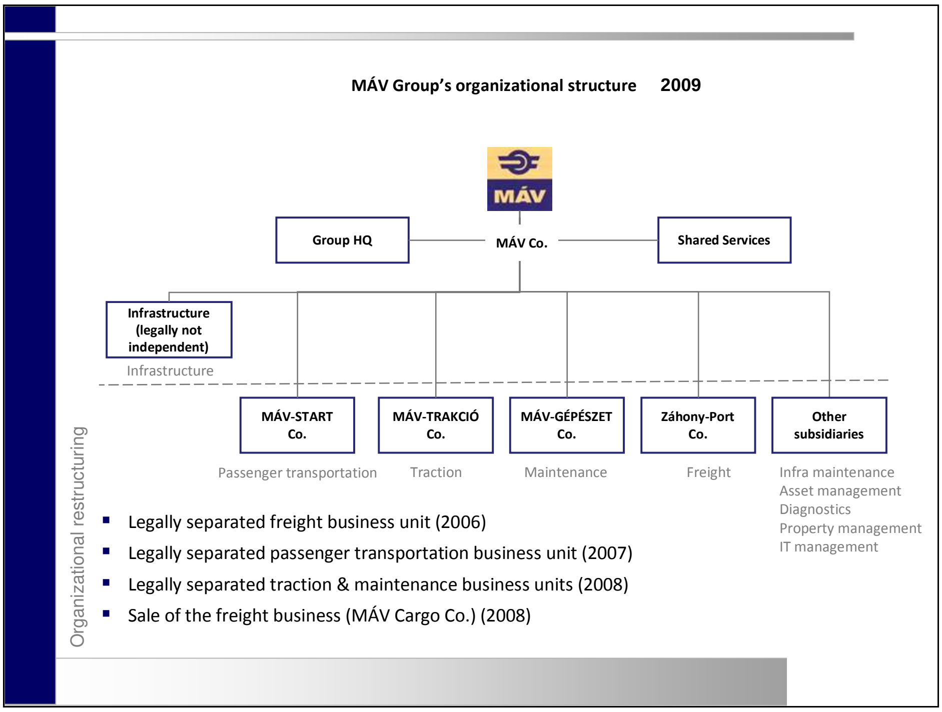

Figure 3. The main milestones of organizational restructuring of MÁV Group – 2009 (Source: MÁV Co. IBU)

The market operability of the railway sector can be ensured if the state concludes contract for the providing of the rail passenger public service and the operation of the railway network system, and through the state budget it guarantees the long term operation of railway undertakings engaging public service obligation [5]. In addition further downsizing, decreasing of the infrastructure services and costs are also possible, which will establish new companies that can provide the additional services contained by the Vtv. Annex III. more effective to the railway undertakings with network access entitlement [8].

So in case of providing traction current, supply of fuel, shunting (shunting locomotive, shunting locomotive staff and/or shunting staff of IM) new, specialized companies are expected to appear on the market.

The changing opportunities mentioned above provide for the IM's wide spectrum to expand their business activity. This can mean other economic size and role, as well as it has clear impact to the rail competitiveness.

1.4. Current situation and opportunities of the Hungarian railway market

The main aim of the Billing and Statistics System for Network Usage (PASS2): The increase of the service providing flexibility with the help of an informatic system comprehending the whole business process.

The realization of the informatic system containing the service request, ordering, providing and accounting activities was in 2009 but the system with its full functionality was commissioned on 1st January 2010.

The former informatic systems (SZIR, TAKT, ATLASZ, KAPELLA, PASS1, RES, SZVM, etc.) operated individual and isolated from each other and covered only certain elements of the business process. By the creating of the business process integrity MÁV Co. IBU can achieve the registration of the real ordered services, the insert of the station activity, the real time logging and the appropriate warrant of the track access charges. The market players expect the increasing efficiency of the infrastructure service providing process from the total installation of this informatic system.

2. Infrastructure services and the access procedure

2.1. The provided infrastructure services

The clients of the Infrastructure Business Unit (IBU) are the railway undertakings with operation licence, safety certificate and network access contract who can resort to the infrastructure services provided by IBU.

The basic, supplementary and additional services provided by MÁV Co. Infrastructure Business Unit can be found on the website of the Rail Capacity Allocation Office Ltd. (VPE) while the ancillary and other services can be seen on the homepage of MÁV Co.

2.2. Conditions of the service request

2.2.1. Regulatory environment

According to the current regulations the railway undertakings need to have operation licence, safety certificate, first train path granted by the rail capacity allocation office and network access contract concluded with the infrastructure manager to use the open access railway network.

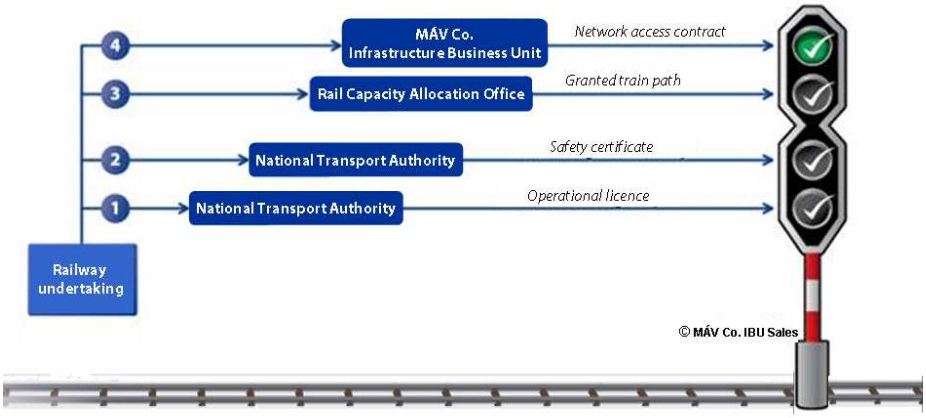

Figure 4. Network access conditions (Source: MÁV Co. IBU Brochure [6])

Regulatory Body is responsible for granting operation licences and the independent market control and monitoring activity. Transport Authority is responsible for issuing safety certificates, controls the observance of the regulations and instructions concerned the transport safety. Both spheres of activities belong to National Transport Authority as organisation.

Network Statement contains the infrastructure services and their charges, the access conditions of the railway network, the features of the infrastructure, the procedure and terms of the capacity allocation.

The infrastructure manager and the railway undertaking conclude the network access contract founded on the valid Network Statement. The Annex 1 of the Network Statement contains instructions concerned the contain of the network access contract.

2.3. The request procedure of the infrastructure services

<u>Request procedure in the informatical system of VPE</u>

The use of the infrastructure services defined by the Vtv. 3. Annex I-III. (basic, supplementary, additional services) have to be ordered by the railway undertakings via internet, in the train path allocation system called KAPELLA (www.kapella.hu)[9]

<u>Request procedure in the informatic system IÜR of MÁV Co.</u>

The infrastructure services not included in the Vtv. Annex I-III. should be ordered in the Integrated Customer Service System (IÜR) of PASS2 system.

<u>Handling of the ordered and allocated infrastructure services</u>

The current service request system consists of two elements. The basic, supplementary and the additional services will be judged and allocated by VPE to the railway undertakings while ancillary and other services are managed by the MÁV Co. Infrastructure Business Unit.

Independent from the type and the place of the ordered services the requests appear in the MÁV Co. Infrastructure Business Unit's informatic system, PASS2, so that railway undertakings can see all of their own requests in the IÜR system.

Further advantage of PASS2 that the staff of MÁV Co. Infrastructure Business Unit who takes part in the service providing can see the ordered services of railway undertakings at the same place. The PASS2 Logging System transmits the ordered and fulfilled service data directly to the accounting module of the system so the railway undertakings will pay only for the actually used services.

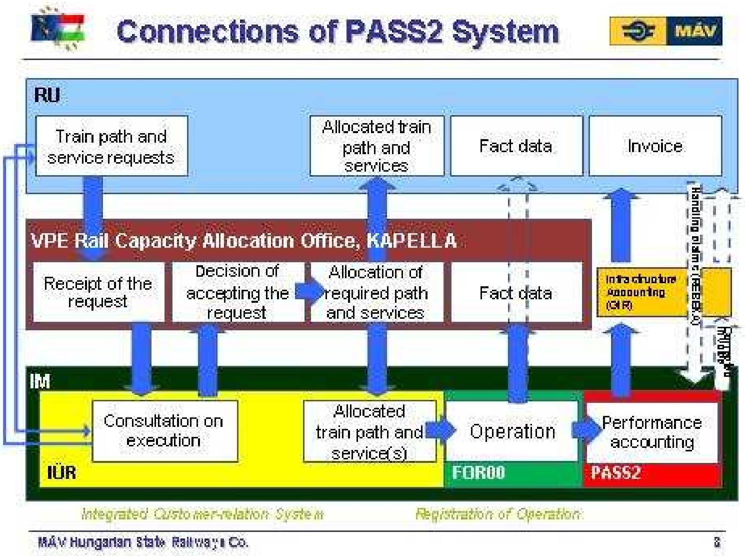

Figure 5. PASS2 system (Source: MÁV Co. IBU Sales Department)

The integrated operation of the KAPELLA and the PASS2 systems allow for the railway undertakings the more flexible adaptation to the freight needs, because the rail capacity allocation office can accept the request and allocate the train path even one hour before the train departure and at the same time the MÁV Co. Infrastructure Business Unit can start and run the trains thanks to the development of the IT system.

3. Customer satisfaction study among MÁV IBU's RU clients

The MÁV Co. Infrastructure Business Unit has started to monitor the level of its customers, the railway undertakings having network access contract, in 2005. The research methodology was altered considerably in 2007 to reveal more exact answers and to identify the background reasons, opinions, attitudes and experience deeper in detail.

The main objectives

- To learn customers' opinion about performance of IBU on key service areas
- To reveal the reasons and experience causing the unfavourable evaluations
- To detect the direction and importance of opinion shifts
- To learn the customers' suggestions in connection with service development
- To provide quick information regarding current topics
- To provide possibility to unfold any subject regarded by our clients important
- To determine the focuses we should concentrate on to increase the satisfaction level of our customers

3.1. Research methodology

Qualitative, F2F in-depth interviews based on structured scenario. The target group is the circle of RUs having network access contract with MÁV Co. in a designated time point, which is determined so, that it can involve the most clients, who have valid opinion[1] about the examined year (in 2009 23 firms). Within the company the relationship managers or/and other professionals are the respondents.

Examined subjects - 5 blocks

Contracting; (duration of contracting process; compensation)

Billing; (precision; performance collation; cooperation readiness)

Service providing; (missing services; train running; shunting; service availability; network; stations; service staff; information)

Colleagues in headquarter and in regional centres

Current topics

[1] Therefore the sample size is not definitely the same as the end-of-year number of customers.

Applied scale system

- 5-point verbatim scales, tailor-made phrasing of the anchor points suitably to the particular question. Form of card set avoided the connection with the Hungarian school qualification system.
- Values from very favourable to very unfavourable.
- Middle value is acceptable to avoid the neutral answers, to gain the acceptable level, to enforce choices.

In case of unfavourable opinions respondents are asked to explain freely their detailed reasons in the framework of an open-ended question not influenced by pre-coded answers.

The interviews concerned year 2009 were conducted January – March, 2010, in order that the partners could evaluate the whole year in such a period, which is not so busy from business aspect.

3.2. Most important factors affecting the analysis

The sample size basically enables qualitative approach, thus statistical calculations can be applied with indicating value only, mainly as demonstration tools. Therefore the analysis focuses on the opinion patterns and tendencies.

Weighting procedure cannot be applied because of the small sample size, in addition the present share structure of our partners is so disproportionate, that the prevalent customers' opinion would almost entirely overwhelm the others'.

The sample size gives possibility to the very simple "segmentation" only (e.g. old partners - new partners). In 2009 the new partners had less experience and more favourable evaluation attitude.

It managed to ask the whole target group three years in row (see Figure 6).

3.3. Main results 2009

Alike the previous year the performance of our colleagues (both in the headquarter and in the regional centres), as well as of the billing were the best and they are developing.

Contracting was the area which developed the most during 2009, and it managed to shift out of the negative range into the acceptable territory.

The general evaluation connected to our service providing activity was formed by joint effect of different directional factors. Though the cumulative performance average was below the acceptable level and the general trend was rather stagnant to reach real picture we should have seen behind average: in case of some elements (running of trains, shunting) we could improve characteristically above the acceptable level, however the quality of our infrastructural offer retained the general result in the negative range.

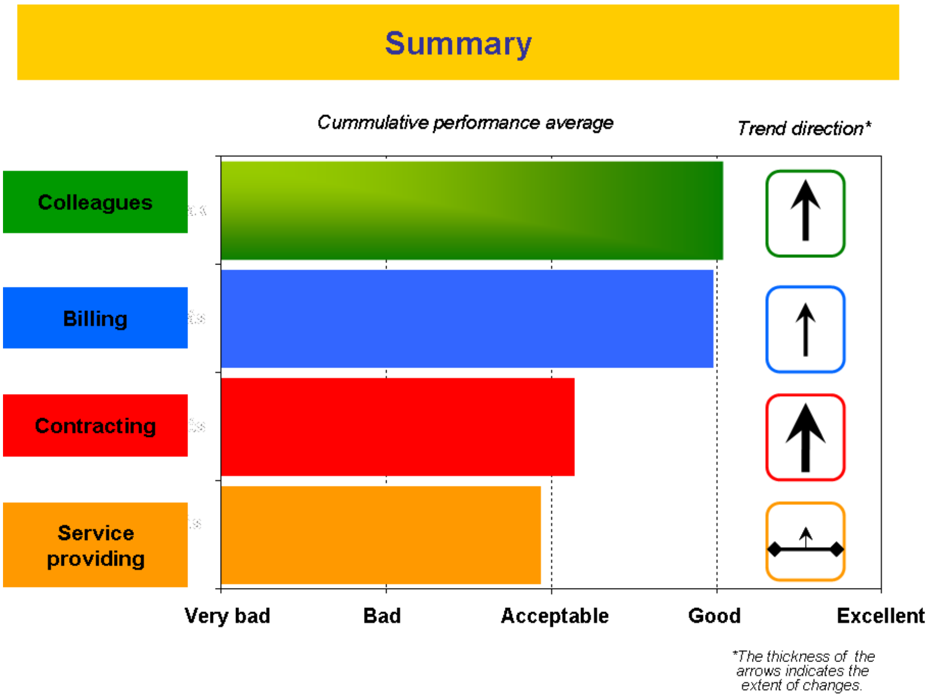

Figure 6. Summary of the customer satisfaction results 2009 (Source: MÁV Co. IBU Sales Department Customer Satisfaction Study)

On the whole, slightly increasing tendencies could be perceived in the satisfaction level of MÁV Co. IBU's customers, however, this development was more moderate among the older, more experienced clients.

The total opinion pattern summary chart shows how the inside structure of answers changed during the last three years which the same survey method was applied in. It can be observed that the roughly equalized shape (2007) developed to an opinion pattern with an unambiguous positive dominance, but also with a strong negative side (2009).

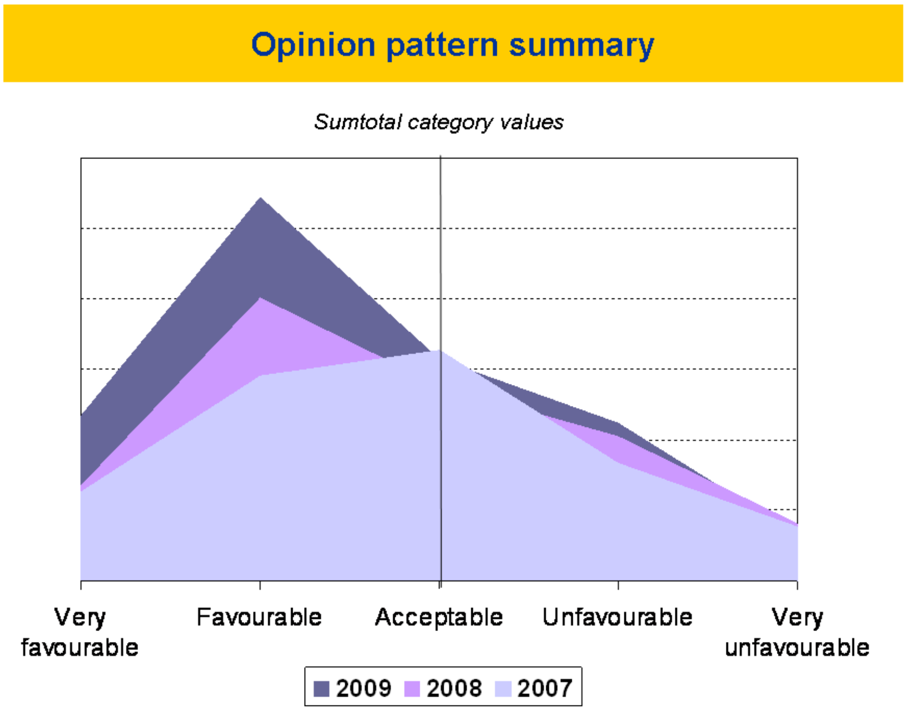

Figure 7. Total opinion pattern 2009 (Source: MÁV Co. IBU Sales Department Customer Satisfaction Study)

One of the main directions of further research development is the deeper involving of other professional departments.

Based on the results of the survey a detailed measurement plan was formed to increase customer satisfaction level. The management considers the fulfilment of this plan one of their important tasks.

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A Fuzzy Bacterial Evolutionary Solution for Three Dimensional Bin Packing Problems

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Abstract This paper presents an evolutionary solution for a commonly occuring task, the three dimensional version of the bin packing problem. The algorithm presented here is a variation of bacterial evolution, and also utilizes fuzzy logic in its fitness calculations. The goal is to give a useful alternative method to the basic problem, and to demonstrate that the addition of fuzzy logic to the fitness function benefits the speed of the evolutionary process. The paper first describes the specific problem, then moves on to detail every key part of the algorithm. Finally, the results from a number of test runs are used to show the general effectivess, and the contrast between the two versions.

Keyword: bin packing, three-dimensional, bacterial algorithm, fuzzy logic

1. Introduction

Almost any kind of general bin packing is difficult to create algorithms for, which is mainly due to the fact that these tasks are NP-hard. Even to its simplest forms, without any additional restrictions, only approximate solution methods can be given, barring some special cases. The basic problem may have multiple interpretations, the one presented here utilizes a certain space known as the container, by placing objects inside it, in order to cover as much of the container as possible. The restriction is that there may be no overlapping of the objects, nor can they have parts sticking out of the container [4] [5] [7] [8].

The bacterial evolutionary algorithm is a versatile optimization method that imitates phenomena observed in the reproduction of microbial organisms. It is a member of the family of evolutionary algorithms, which means that it uses stochastic mutations and inheritance to produce new candidate solutions to a problem. These candidates are known as individuals, and together they form the population on which the bacterial algorithm operates. The individuals can be broken down to segments known as genes, which, when combined, describe a full solution candidate. The goal of the evolutionary process is to create successive generations, each of them containing better solutions than earlier ones [1] [2].

Applying fuzzy operations to the evaluation of individual fitness in evolutionary algorithms can be beneficial [11] [12]. In one of the implementations of bacterial evolution shown here, fuzzy elements are introduced to the fitness calculations by assigning membership values to every one of the genes. This is done because most of the candidates have redundant genes, which have to be culled in order to find the real solution. The paper presents all the important components of the algorithm, and its effectiveness of both its fuzzy and non-fuzzy (crisp) versions with benchmark problems.

2. The Problem

The three-dimensional bin packing task in our case is limited to rectangular objects. The container and the bins can be defined with three numbers, denoting their dimensions. Thus, the full description of the problem has the following parameters:

- The dimensions of the container
- The dimensions of every type of bin object
- The number of bins of each particular type

The problem itself can take multiple forms, for example to use as few containers as possible to pack a certain set of bins, or to utilize a single container to the fullest extent possible. Although these variations might have a lot in common, the best algorithm solutions for them do not necessarily correlate [3] [4] [7] [9]. The goal of the algorithm here is the latter, to use as much of the container space as possible, only picking from bins still in the supply. Another restriction is that the edges of the bins have to be either parallel or perpendicular to those of the container, which limits the number of possible orientations, but greatly simplifies calculating if and how much they overlap.

3. The Bacterial Evolutionary Algorithm

As mentioned before, the bacterial evolutionary algorithm works on principles of reproduction as seen in the case of bacteria. The method works on a population of individuals, each of which fully describe a solution to the problem. The population is constantly refreshed through cycles known as generations. The individuals in the new generation inherit their parts from older members of the population they were created from. These blocks of heredity are way to model genetic information in biological organisms. The interpretation of what a gene is can vary from one evolutionary algorithm to the next.

Simulating the phenomenon of natural selection makes sure that individuals that are better get to take more part in creating the next generation, by having more offspring than the ones that are less suited to the problem. Also through a process known as horizontal gene transfer, better individuals can also spread parts of themselves within the population, as it will often correlate with better solutions [1] [2].

In order to measure how good a solution is, a scale called „fitness value” is introduced. Members of the population that have a higher fitness value are considered to be better solutions, and they have more chance of producing offspring. Performing a generation of a bacterial evolutionary algorithm consists of doing the following:

- Cloning: In this step, we make copies of individuals, which will then be subjected to mutation.
- Mutation: This part of the algorithm performs random alterations on the clones
- Replacement: The best clones are then used to replace the parent individuals, if there is any improvement.
- Gene transfers: In this process, members of the population that fall into the better portion can copy some of their genome into worse individuals, hopefully improving them in the process [1] [2].

Since any individual created by these operations has to represent a solution candidate, special care must be taken to ensure that they do not result in individuals with flawed syntax. For example, the gene transfer step, instead of copying over random bits, has to work with bins as units in order to make sense in the context of the problem. The bin packing problem can be put into evolutionary terms in a number of ways [5] [6] [8] [9] [10] the following interpretation operators are based on these ideas.

3.1. An Individual

The way an individual is stored is relatively simple, given the description of the problem (the container size and the supply of different types of bins), the following are sufficient:

- The number and indices of which bins from the supply are used
- The position and orientation of each of these bins in the container
- Various other values, such as stored fitness measurements

The position, orientation, and supply index of every bin is considered a gene in and of itself, and they may be changed independently of other bins, however, they are bound in the sense that none of them may be removed or copied without also taking care of the other parts.

3.2. Introducing New Members into the Population

The simplest new solution candidate would be a container having no bins in it, and while it definitely works for this algorithm, randomized individuals are used at the start, and they are also introduced into the population during later generations, to help keep up genetic diversity. They are created by randomly choosing a number of bins to place in them (based on an average), and using the addition operator, which will be described later.

3.3. Cloning and Mutation

This operation has multiple components because of the different alterations that an individual can go through. The cloning portion is simply done by copying a solution bin by bin, but the mutation part consists of multiple actions, which include adding new bins to an individual, changing the position of bins already in the container, and removing some of them. The number of these smaller operations within a single mutation is random, with a geometric distribution, determined by an average. The operators presented here are mostly based on common bin packing heuristics [3] [4] [7] [8].

3.4. Adding New Bins to an Individual

The addition of a new bin to a solution candidate is a relatively simple task. We choose one from the supply, then find a random position and orientation for it. The orientation is handled by creating a random permutation of its three dimensions, but the positioning requires some help in order to be efficient. From the randomly generated initial place, the bin is moved towards the nearest other bin or a wall of the container, as close as possible. This, however, is only done if the bin is not at a sufficient distance from everything else, so the solution can be built starting from multiple points at once.

The probability of adding new bins is directly proportional to how far the total volume of the existing bins is from the total volume of the container:

$$P_{add} \sim \max\left(1, P_{min} + \frac{V_{container} - \sum V_{bins}}{V_{container}}\right). \qquad (1)$$

3.5. Moving Bins

The probability of this specific operation depends on the number of bins in the solution:

$$P_{move} \sim \frac{V_{avg} \cdot n_{bins}}{V_{container}}, \qquad (2)$$

where V_{avg} denotes the average volume of the bins found in the supply. The chance of choosing a particular bin is inversely proportional to its distance from the closest other bin or a wall, provided that this distance is above a certain limit (this keeps tightly fit sections the way they are).

The moving itself consists of two parts; first, an offset vector is generated randomly, and if it exceeds a certain number in magnitude, the bin is moved in that exact direction and to that distance. However, if the offset vector is sufficiently small, the nearest side of another bin or wall (in that direction) is the destination. This might mean moving in the opposite direction, in case of an overlap.

3.6. Removing Bins

The removal of a bin from the solution is a straightforward operation, the only questions are how frequently is should be done, and which bin to choose. There is a minimum non-zero chance for removing any of them in a given mutation, but for the most part, the probability is determined by the total volume of bins in the solution. The closer it is to the total volume of the container, the more useless bins there are in it, therefore the higher the probability of bin removal, similarly to the addition operation:

$$P_{remove} \sim \max\left(1, P_{min} + 0.5\,\frac{\sum V_{bins}}{V_{container}}\right). \tag{3}$$

The probability of choosing a particular bin is proportional to how much it overlaps with others. If all of them are completely separate, the operation does nothing.

3.7. Gene transfers

The purpose of horizontal gene transfers in this case is to make the receiver individual, the one that the genome segment is copied to, better. For this, it makes sense to group parts of the solution that are spatially connected, since the goal here is effective utilization of space. This translates to bins that are within a certain section of the container.The section is chosen randomly, and any bin from the source individual that is at least partially within this section is placed in the same place in the destination individual.

To make room for the new bins, any of them in the destination individual that are not completely outside the section are removed, as well as any bins that are outside, but share the same index in the supply of bins as the ones that are about to be copied over. This prior correction makes sure that there are no irregular solutions along the way. The gene transfer may introduce additional overlaps, which could be avoided by only copying bins that are completely inside the section, and only keeping ones that are completely outside of it. This, however, would introduce problems such as often creating holes in the destination individual, by cleaning a portion of the container space, and not adding anything in return.

As an illustarion, in Fig. 1, if we are looking at the source individual, bins 1 and 2 are the ones that will be selected for transfer. However, if this were a destination individual, bin 3 would be the only one of the three still included after the transfer.

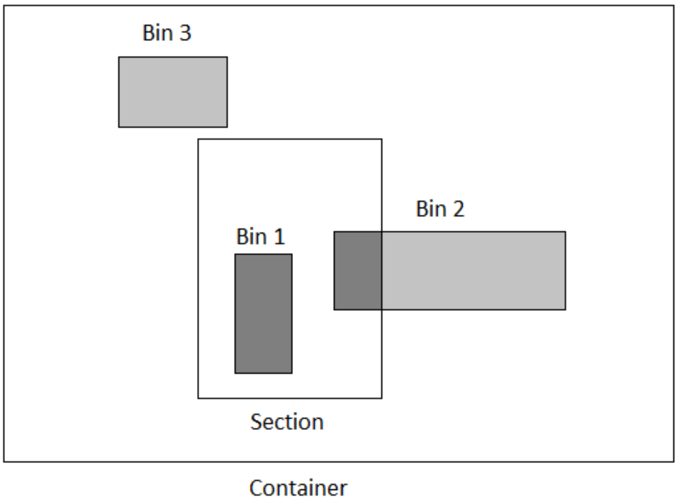

Figure 1. Selection of bins in the gene transfer operation

4. The Fitness Function

Since the fitness function is what drives the entire evolutionary process towards better individuals, it is important to choose an appropriate one. In our case, because there are less restrictions on the candidate solutions than there are in the final one (due to the permitted overlapping), two separate measures are used. The first one represents the goodness of the solution after temporarily correcting for overlapping, either by repositioning or deleting the problematic bins from it. The second one, in contrast, calculates the usefulness of the candidate before these corrections. There is a difference in priority between these two measures; the first one is more important for determining the viability of an individual, but due to its discrete nature, another, secondary fitness value is needed as well.

The primary fitness value, which represents the viability of the actual, corrected solution, is calculated after a series of operations that remove any remaining overlapping between the bins. Once this is done, a summation of the selected bin volumes gives a good indicator as to how well the container space is utilized:

$$fitness_{primary} = \frac{\sum V_{remaining\ bins}}{V_{container}} \tag{4}$$

The elimination process itself is stochastic; in each cycle, out of the bins that have any overlapping, one is chosen randomly. The probability of removal is directly proportional to how many others the particular bin overlaps with. All individuals are evaluated in every generation, not only after modifications (mutations and gene transfers), so that even if there is no change, a different random elimination order might yield better coverage, which updates the primary fitness value as well.

Calculating the secondary fitness value has two separate versions; one that uses fuzzy membership functions to handle bins that are fully or partially covered by others, the crisp version, on the other hand, treats the overlaps separately.

4.1. Crisp Version

The secondary fitness value, in the crisp case, imposes a penalty on any overlapping between bins (or pairs of bins, to be more precise), and is calculated in the following way:

$$fitness_{secondary} = \frac{\sum V_{bins} - C \cdot \sum V_{overlaps}}{V_{container}}, \quad (5)$$

where the constant C might be any real number above 2. Obviously, the higher the number, the less lenient the algorithm is towards bins that share common space. The value used in the test runs was 8.

4.2. Fuzzy Version

The fuzzy variant of the secondary fitness function is somewhat similar to the crisp version, but it deals with overlapping differently:

$$fitness_{secondary} = \frac{\sum (V]_{bin} \cdot \Lambda_{bins} [F_{bin})}{V_{container}}, \quad (6)$$

where F_{bin} is the measure of how much of a bin is not covered by another, a ratio between 0 and 1. Here, it is used as a membership function for expressing how much of a part a bin has in the solution. A conjunction of all the F values for a bin (from each of its overlaps)is taken as the final membership value, an operation that is kept to its simplest version by using their minimum.

In both cases, fitness comparisons between individuals are done by first taking the primary value into consideration, and the secondary values are only used if there's no significant difference in the primary ones (this means more than a sufficiently small non-zero number, to account for floating point imprecision).

5. The Benchmark Problems and Parameters Used for Comparison

The specific problem files for the tests were acquired from [13]. The tests were run 20 times for each set of parameters, and then the results were averaged, to mitigate the variance that results from the stochastic nature of the algorithm. There were three different population sizes, 20, 50 and 100. The average number of sub-operations in a mutation was 5, and the populations underwent a total of 10 gene transfers in each generation, regardless of their size, Also, 3 new individuals were placed in the population after every generation. The best member of the population at any given time was immune to replacement (except by even better clones), which is known as elitist strategy. It was put into the algorithm to ensure that the best solution never gets lost because of alterations to the individual. The test runs had a common time limit, 10 minutes in every case, which served as the basis for comparing their effectiveness.

6. Observed Results

As Table 1. shows, the general tendency during the tests was that the 50-member populations had the best performance in the allotted time. The inclusion of the fuzzy values in the membership function, in general, meant about 3-4% of average fill rate improvement.

Table 1. Average final utilization of containter space with the various algorithms

Population size	Problem 1 crisp	Problem 1 fuzzy	Problem 2 crisp	Problem 2 fuzzy	Problem 3 crisp	Problem 3 fuzzy
20	68%	71%	70%	73%	71%	75%
50	70%	72%	74%	76%	77%	80%
100	65%	69%	70%	72%	75%	77%

7. Conclusions and Future Improvements

Overall, the inclusion of the fuzzy membership of bins proved to be beneficial when it came to final results. The performance of the algorithm seemed to be largely dependent on the size of the population, which might be due to the number of gene transfers and new individuals in every generation, which stayed the same. They have opposite effects on genetic diversity as the population size changes, and 50 may have been a better, middle solution than the other two.

There might be several changes or extension to the core methods of the bacterial algorithm implemented here, namely the mutation and gene transfer operations. New heuristics might improve their effectiveness, making them more suited to this specific problem of bin packing. Also, the fitness function may also undergo changes, to reflect different packing heuristics than the ones used here. Finally, part of other evolutionary methods, such as crossover-based genetic variants might also be included as an extension of the bacterial one [12], or perhaps with multiple populations run in parallel.

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New Distribution Models on Commercial Logistics

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Abstract Traditional division of labor between manufacturing and trading companies is currently changing. The trading companies take more and more over distribution logistic tasks of the manufacturers. Previously it was the responsibility of manufacturing companies to deliver goods for trading companies who should handle only the sale of goods. The main purpose of this paper is to illustrate the development of distribution logistics and describe application possibilities of a new model called "pick it up logistics".

Keywords: Distribution logistics, warehousing costs, transportation

1. Introduction

The main task of distribution logistics is to transfer commercial products from producer to consumer by using the available resources efficiently satisfying basic principles of logistics and manufacturer and consumer expectations. The product forwarding is realized through complex and diversified distribution networks. These distribution models have evolved in different way depending on the country, transportation infrastructure and geographical position [5]. Organizing physical distribution requires the solution of several problems which are closely related. At first system elements - distribution network, warehouses, transportation modes, vehicle fleet etc. - seem to be independent from each other; however in case of system development these elements should be handled globally.

2. Demonstration of traditional distribution system

2.1. Direct distribution

In the beginning the development of distribution logistics products were transported directly from manufacturer to consumer. In these cases insertion of certain logistics nodes was not necessary. Of course this kind of distribution model exists till present day but their application is rare because higher costs.

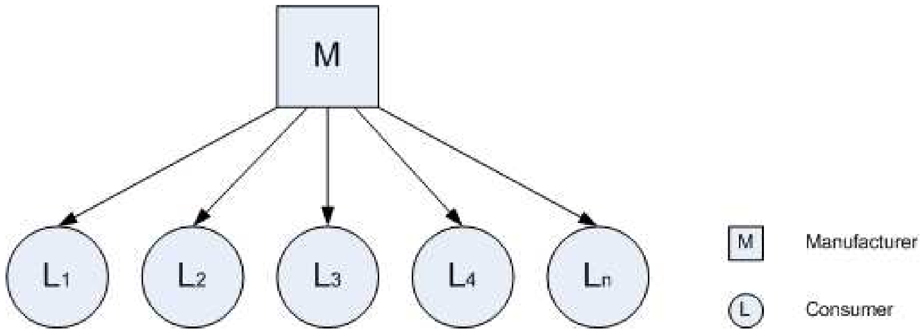

Figure 1. Direct distribution (authors)

2.2. Indirect distribution

Today's requirements promoted the development of multi-stage systems in distribution logistics. The number of stage levels is influenced by several reasons like specific supply - production systems management features, inventory optimization and ensuring goods for consumers at any circumstances.

Multi-stage distribution can be implemented and operated without inserting commercial activity (3PL - Third Part Logistics). According to current trends multi-stage distribution systems are not organized, operated and controlled by manufacturers and traders, but by logistic entrepreneurs [6].

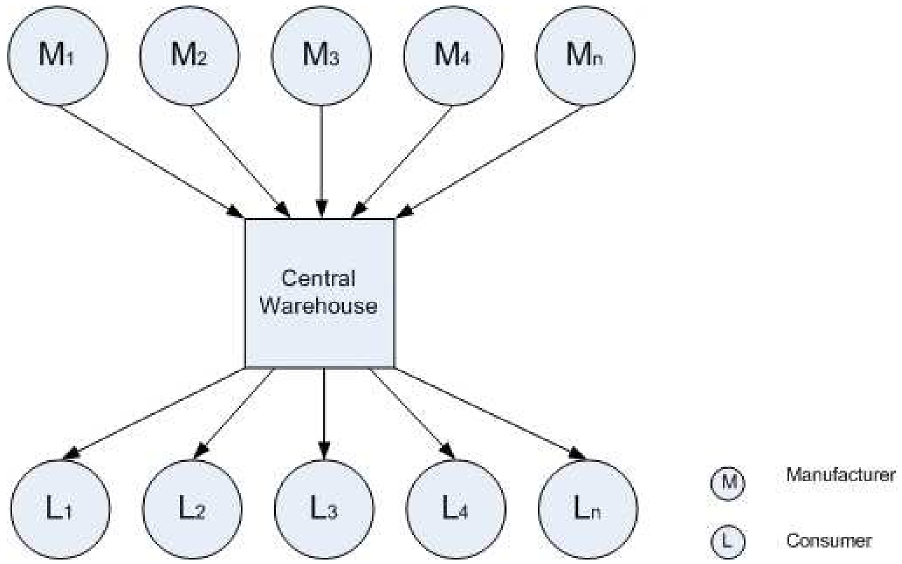

Figure 2. Indirect distribution (authors)

However in several cases it is reasonable and appropriate for traders and manufacturers to organize and manage themselves the logistics system. The following part of the paper deals with the analysis of economical features and efficiency of systems organized by traders.

3. "Pick it up logistics" as distribution system

Traditionally freights are organized according to the following procedure: manufacturer delivers or pays for delivering goods to trader (primary loop); after that trader organizes deliveries from central warehouse to retailers (secondary loop)

"Pick it up logistics" distribution system aims to modify relationship of manufacturer and trader by excluding manufacturer from the organization of distribution. This results in significant cost savings. According to [1] manufacturers have to face the fact that traders take away the control of logistic activities. This may happen in one or two steps.

The following schematic figure shows the logistic activities organized by trader.

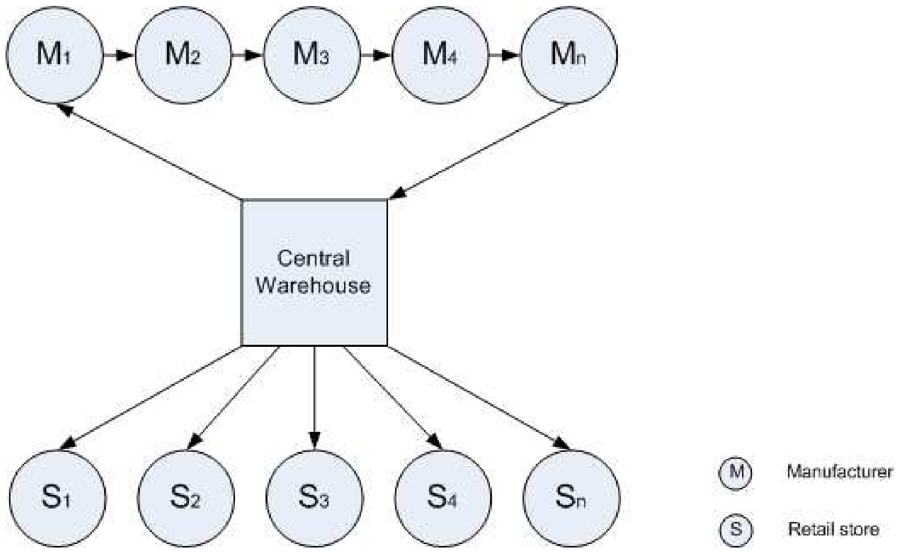

Figure 3. „Pick it up" distribution (authors)

This paper would like to emphasize the fact that the theory described above is more and more widely spread. According to this theory organizing tasks are taken away and primary loop is organized by trader.

This method could be the opportunity for traders to decrease their costs.

Pick is up logistics means that trader or its contracted logistic service provider does not pay delivery costs for manufacturer but directly transfer the goods itself.

The takeover of goods can be at three different locations:

- harbors (in case of oversea import goods)
- at manufacturing plants
- at warehouse or commercial center of manufacturer

This situation can be advantageous: on the one they get better negotiation basis against manufacturers; on the other hand they can realize cost savings.

According to [1] theory cost savings derive from the following resources:

- Absence of additional costs charged by manufacturers. Manufacturers often charge traders more than actual logistic cost.
- By consolidation of more deliveries traders may reach lower delivery cost compared to that case when manufacturer order delivery service individually.
- By avoiding unnecessary deliveries and intermediary storages in the network between manufacturer and trader.

The “Pick it up logistics” often outgrows to global dimension by stretching through country borders of trader.

4. The study’s base case

With the above mentioned distribution system the following question comes up:

Whether the savings can be achieved in all cases with the application of "pick it up logistics"?

The study's base case is looking to answer this question with the aid of a simplistic mathematical model.

The theoretical cases examined by us will use fictional Hungary based company with a central warehouse and numerous retail outlets. For the analysis' starting point we selected the following current market trend - when producers deliver to a central warehouse and then the distribution to the retail outlets is performed by the company.

We will examine the situation where some of the slow selling products in our central warehouse that occupy a large area of space therefore increasing the storage fees.

4.1. Quantifying the study

The question is, is it cost efficient for the company to bring the products from the producers to the central warehouse. The possibility of cost reduction could be accomplished by merging orders, plus inventory, storage cost decline, since is sufficient to deliver the amount of goods than can be delivered to the retail outlets.

In this case is not neccessary for the suppliers to produce goods for a longer period of time in order to take advantage of the maximum transport capacity of their vehicles or sending vehicles with underutilized load capacity, therefore decreasing the transport costs both at the supplier and the central warehouse. In order to maintain the service level and to improve their competitive positions the suppliers are trying to fulfill their customers' smaller orders which in turn justifies the use of smaller or underutilized vehicle capacities. The takeover of deliveries should only be considered for suppliers that have slow selling large quantity products.

The transport to the central warehouse and from there to the retail outlets probably utilizing high capacity vehicle and low cost transport method. Ordinarily the specific expense using a small capacity vehicle is 3 to 5 times more when compared to the specific expense of a larger vehicle that is capable transporting a large lot at the same time.

We merely perform analysis on the physical distribution level costs, only transport, storage and handlings expenses are examined.

We perform expense analysis in two cases:

- The suppliers deliver the orders separately to the central warehouse

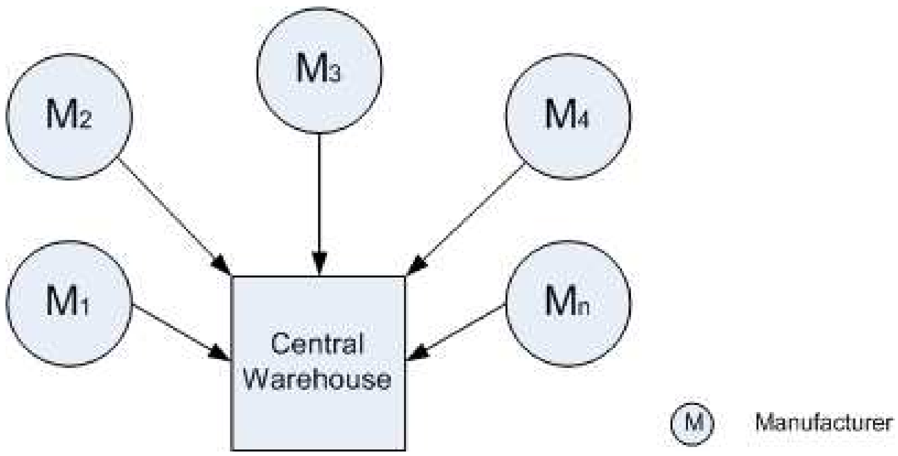

Figure 4. Delivering to the central warehouse (authors)

- The company collects the given amount of products utilizing either their own or rented vehicle fleet.

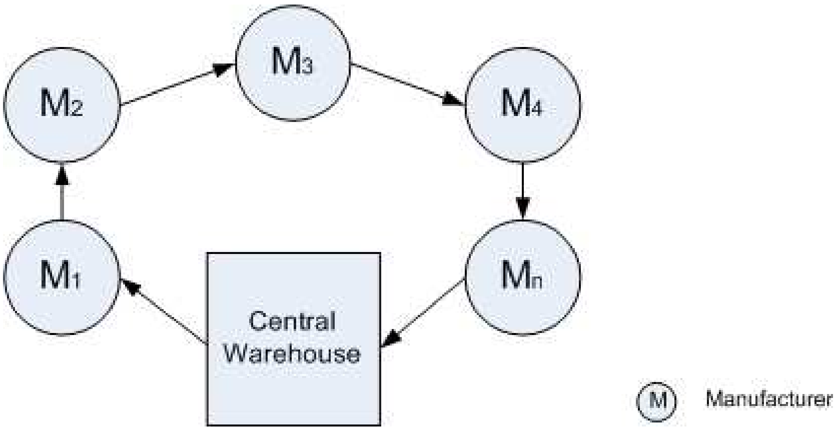

Figure 5. Importing the products to the central warehouse using collecting routes (authors)

We don't examine in the first round those producers whose products are produced in large quantities and are able to deliver economically to the retailers, however we think is important to mention that even is these situation is worthwhile to examine the usefulness of the "pick it up logistics" which we can realize with the linking of the first round and the second round.

In a mixed system [4] we think is conceivable to link locally the retail outlets and the suppliers/producers, so theoretically is possible to link routes, delivering goods in both directions thus cutting down on empty kilometers.

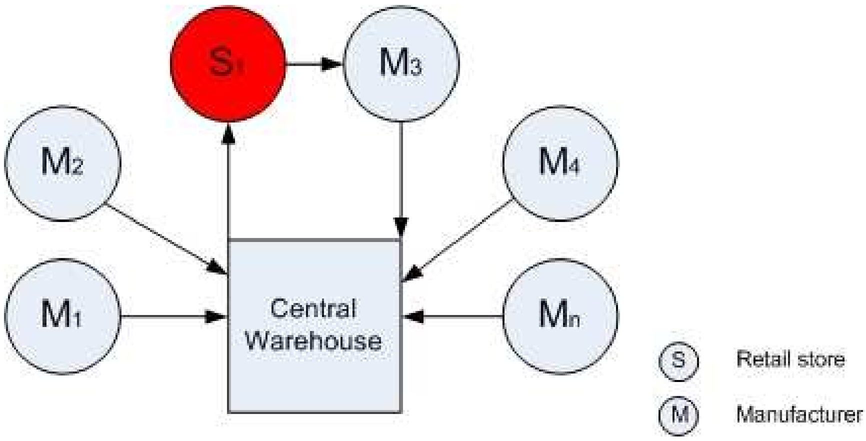

Figure 6. The possible rout-links (authors)

Given is a company with a central warehouse where *P=400* producers deliver their goods, from here *N=200* retail outlets receive the goods (we do not examine the diversity of goods by [8]) . The area is circular; the central warehouse is in P_0.

Consider a small commercial unit where the product average daily order quantity is q_0, in our case *12* tons. The available fleet capacity is G and in our case, because of the favorable unit cost of the vehicles consists of 24 ton vehicles with running costs *KF 200Ft/km*. Thus according to the simplified calculation if on the first day all *200* companies bring in their *4* daily goods, then there is *4* days worth of stock that needs a turn:

$$J = \frac{N * q_0}{G} = \frac{200 * 12}{24} = 100 \text{turns} \tag{1}$$

In the case of a circular area the suppliers average distance [2] by 2/R, where R is the area's radius.

$$\overline{d_k^{circle}} = \frac{2}{3} * R \tag{2}$$

The average distance for a supplier from the central warehouse is 115 km when we calculate using Hungary's territory.

The producers' average shipping quantity is calculated by the commercial units' demands:

$$q_t = \frac{N * q_0}{P} \quad \text{so} \quad 6 \quad \text{tons/day} \tag{3}$$

Namely with a 24 ton vehicle they can transport 4 days' supply at the same time to the central warehouse, the duration of the transport is 4 days.

Utilizing all the above mentioned data we get the total estimated value of the delivery the following way:

$$K_{delivery} = 2 * \overline{d_k^{circle}} * K_F * J \tag{4}$$

The value in forint is 4 600 000 ft/day. But in this case we have to consider the emerging storage expenses, because on an average both the central warehouse and the producer must store the goods for 2 days.

Stockpiling expense for 1 ton is 150Ft/day:

Storing expenses at the central warehouse [7]:

$$K_k * \frac{p}{2} * N * q_0 = 150 * \frac{4}{2} * 200 * 12 = 720000 \quad Ft/day \tag{5}$$

Storing expenses at the producers:

$$K_k * \frac{p}{2} * P * q_t = 150 * \frac{4}{2} * 400 * 6 = 720000 \quad Ft/day \tag{6}$$

In the aggregate the total expense for the producers' deliveries:

$$4.600.000 + 720.000 + 720.000 = 6.040.000 \quad Ft/day \tag{7}$$

Previously we have seen that the vehicles cannot be fully utilized in all circumstances.

As a result we end up with stock on both sides. If the company chooses the collecting route, is sufficient to deliver the daily quantity therefore disposing of the spare stock.

The total run according [3]:

$$F = 0.75 * \sqrt{T} * \left(1 + \frac{G}{q_t} * \frac{\sqrt{P}}{P}\right) = 0.75 * \sqrt{93000} * \left(1 + \frac{24}{6} * \frac{\sqrt{400}}{400}\right) = 274.46km \sim 275km \tag{8}$$

The import expense:

$$F * J * K_F = 275 * 100 * 200 = 5.500.000 \text{ Ft/day} \tag{9}$$

Looking the the preceding, the company will realize a 9.2% profit if it delivers it's own merchandise.

The profit is largely determined by the amount of ordered goods and how many producers deliver to the company, because if this number is low, less than 50, using the existing calculations the delivery of the goods is unprofitable.

Naturally is not just the number of producers the results can also be influenced by the product type, special shipping requirement, etc.

These variations were not examined during our study.

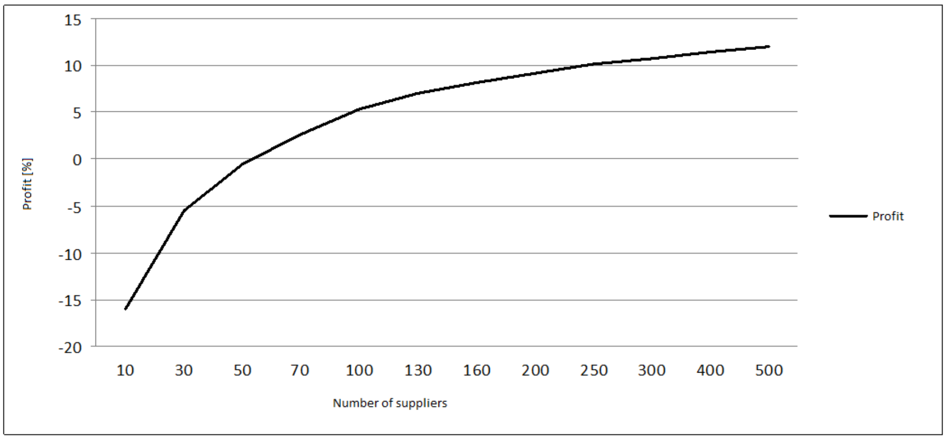

Figure 7. The profit according to the number of deliverers (authors)

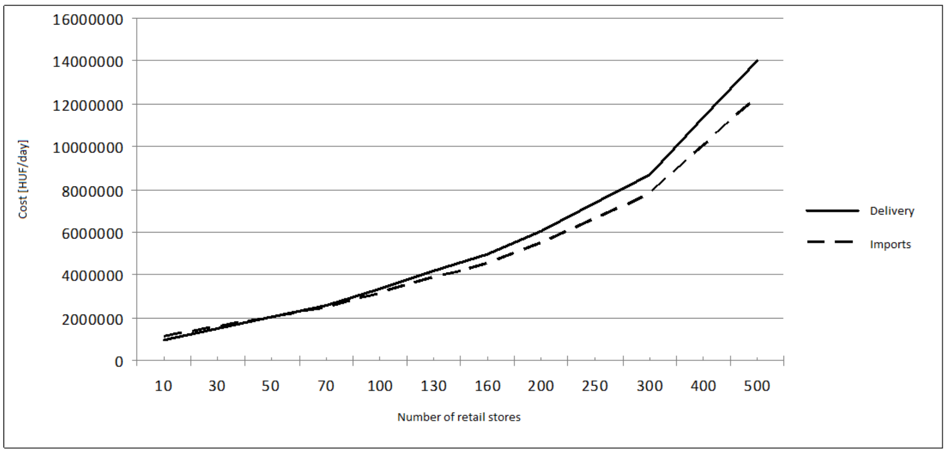

Figure 8. The price difference between delivery and import according to the number of retail outlets (authors)

5. Conclusion

Calculation model demonstrated in this paper also proved that it is worth to deal with “Pick it up logistics”; it is not a coincidence that more and more companies are applying this distribution model.

Of course this procedure is valid for ideal case when all conditions are given for applying “pick it up logistics” which case is rare in practice.

This procedure is very simplified; however in further researches we plan to examine those cases when logistic service providers do not utilize vehicle capacity in 100% or deliveries are done with smaller capacity vehicles. In these cases we can count on increasing delivery costs and decreasing warehouse costs. The conformation of these costs will be examined by further investigation.

It can be generally pronounced that "Pick it up logistics" is worth to deal with, since this new distribution model completed with proper warehouse technology and IT background it can be the resource of significant cost savings.

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Integration of Customer Satisfaction into a Supply Model

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Abstract The utility of supply chain added value is different by various goods or consumers. In this paper the possible values of the utilization and the behavior of this values are inserted into a supply model. The aim of this model is to determine the supply and demand parameters of the utilization of added value, which has great influence on the evolution of supply chains.

Keywords: Supply chain, utilization, value adds in logistics, model

1. Introduction

It is widely accepted that logistics is a management area, which can provide a competitive advantage for companies in the marketplace. If the logistics is well organized and managed, it will increase the value of goods and services. There is a point of view that in the consumer goods market it is not primarily the products, but also the supply chains that compete with each other. The reason is that the products for the consumer are not only pure goods but also a complexity of more different but closely related utilization values. These values are part of a complex value which the consumer sense with buying a product, so they are inseparable and represent a value jointly.

2. Utilization of value adds in the logistics

The following values are built in the current model:

- Utilization of place value – U_p
- Utilization of time value – U_t
- Utilization of application value – U_a

The place value factor of a product represents how a product can be found at the location expected by the consumer [10]. The main object of the consumer is that the purchased product should be as near to the place of use as possible, in extreme cases the place of purchase is the place of use. If this extreme situation is achieved, the place value of the goods for the consumer will be the maximum. As we move away from this point, the place value continues to decrease until it reaches zero. If the place value of the goods is zero, the entire product does not represent a value for the consumer.

The time value factor of a product means for the consumer how he/she gets the product in the expected time. This value has the same nature, it reaches the maximum if the consumer gets the product in the time when he or she wants to apply it. If the consumer gets the product later (or perhaps earlier), the value begins to decrease until it reaches zero. The same rule is valid for this value, if it is zero, the entire product does not represent a value for the consumer.

The application value factor of a product represents its utilization degree for the customer. It means how a product can fulfill its task. This value is created by the producer and the role of the supply chain is to preserve it. It is not possible to determine the maximum utility of the application value in an exact manner as in the case of the utility of the place and time value, because it contains several known and unknown factors. The Kano model for example is suitable for modeling the application value of a product. [9]

As previously mentioned, one value cannot be separated from the complex utility, so for example if a product has a time value of zero, it means that the consumer gets the product with such delay than the whole product-service become worthless. The (1) formula below illustrates the full value of the product for the consumer:

$$U = U_p * U_t * U_a \tag{1}$$

The dual-purpose of the consumer is utility maximization related to the product-, while minimizing the costs associated with the product. Hence these two factors effect each other in opposed directions it is difficult to determine the optimal utility and cost level. The $U_{consumer}$ on Figur shows the possible optimal consumer decisions (decisions with maximum satisfaction) that are for a given utility level the amount the consumer is willing to pay. The progressive nature of the curve is because one unit grow in utility is awarded with a decreasing tolerated cost level. The $U_{producer}$ curve on the same figure is degressive, hence the producer of this given product can raise the utility level with one unit with increasing cost level. Illustrated with an example if a supplier shortens the waiting time from 5 days to 4, than the additional cost will be unity. If the supplier would shorten the waiting time with an other day, than the additional cost would be more than a unit.

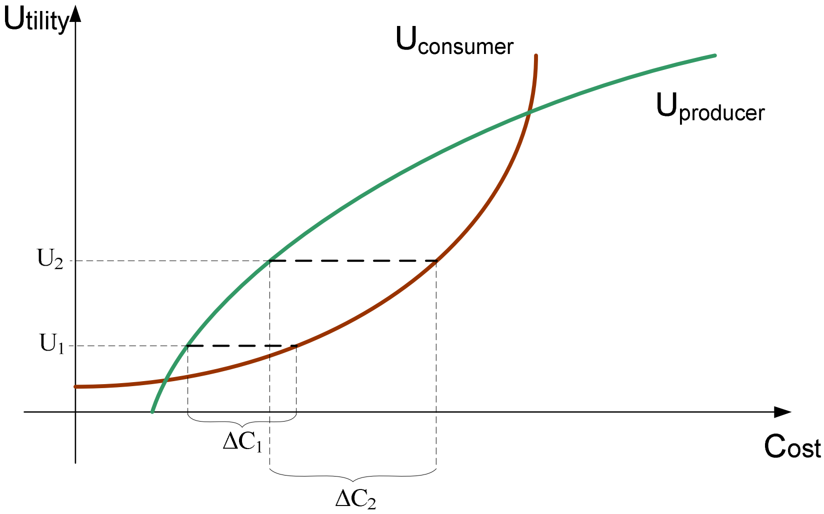


Figure 1. Consumer and producer cost and utility curves

The cost of the product for the consumer means the income for the producer, so the difference between the $C_{consumer}$ and the $C_{producer}$ is the profit margin of the producer. If the producer and the consumer cost-utility curve follow the example above, the aim of the supply chain is to determine the utility point where profit margin (ΔC) is the maximum. This paper presents the utility-cost relationship from the producers' side.

3. Cost of gaining utility factors

Many paper discuss the maximization of customer satisfaction how the logistics can provide the maximum utility of its service. The logistics in this model can provide the maximum utility, if goods are carried to the place and at the time where and when (not after or before) the consumer wants to use them. But many consumer are willing to decrease the utility of the purchase if the cost of the purchase is decreasing also. This chapter shows the costs of the utility factors.

Cost of gaining the place utility

The cost of the place value has a correlation to the transportation cost from the production area to the using area. The most influential factor in shipping costs is the transport length, so it is the independent variable in the context of describing the cost of place value (2).

$$C_p(s) = C_{p0} + \alpha_p * s^{\beta p} \tag{2}$$

Where:

C_p cost of gaining the place value

s transport length between the production and the using area (independent variable)

C_{p0} minimum rate of the cost of place value, it is independent form the transport length ($C_{p0} > 0$)

α_p steepness ($\alpha > 0$)

β_p sensitivity of the time value function, where $0<\beta_p<1$ that means degressive attitude of the place value function

Figure 2. Relationship between the travelled distance and the place value

<u>Cost of gaining the time utility</u>

The cost of the time value covers the goods and resource needs, which ensures that the product can be used by the consumers at the requested time. This relationship is illustrated in formula (3).

$$C_t(t) = C_{t0} + \alpha_t * |t|^{\beta t} \tag{3}$$

Where:

C_t cost of gaining the time value

t elapsed time between the actual and demanded arrival (independent variable)

C_{t0} minimum cost of time value, it is independent form elapsed time ($C_{t0} < 0$)

α_t steepness; ($\alpha > 0$)

β_t sensitivity of the time value function, here $0 < \beta$, because the time dependent cost of goods can be both degressive and progressive

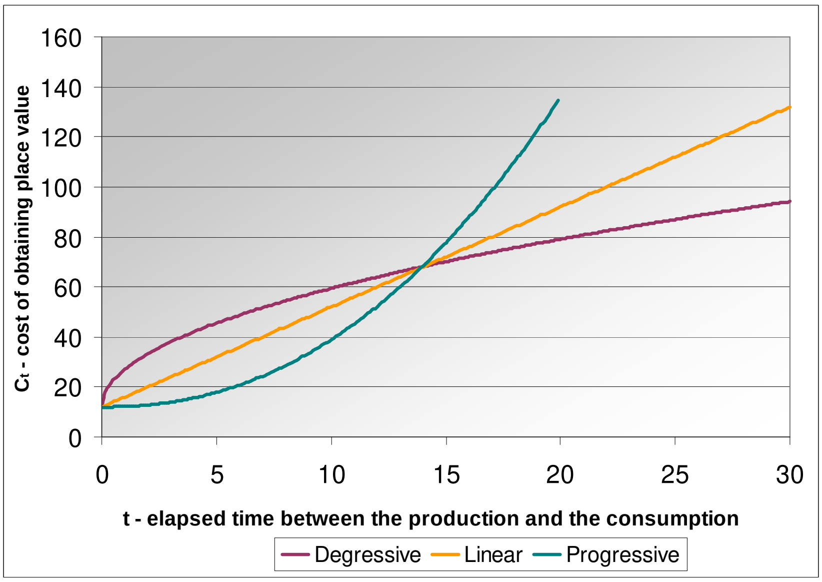


Figure 3. Relationship between the elapsed time and the time value

$$t = \frac{s}{v} \tag{4}$$

Where *v* the speed of shipping.

$$C_t(s) = C_{t0} + \alpha_t * \left(\frac{s}{v}\right)^{\beta t} \tag{5}$$

$$C_t(s) = C_{t0} + \frac{\alpha_t}{v^{\beta t}} * s^{\beta t} \tag{6}$$

Cost of gaining the application utility

The application value of a product related its manufacturing cost. In this model the manufacturing cost is connected with the production area and has a correlation with the wages. So I can assign a production cost and a distance (the distance between the production and the using area) to every possible production area.

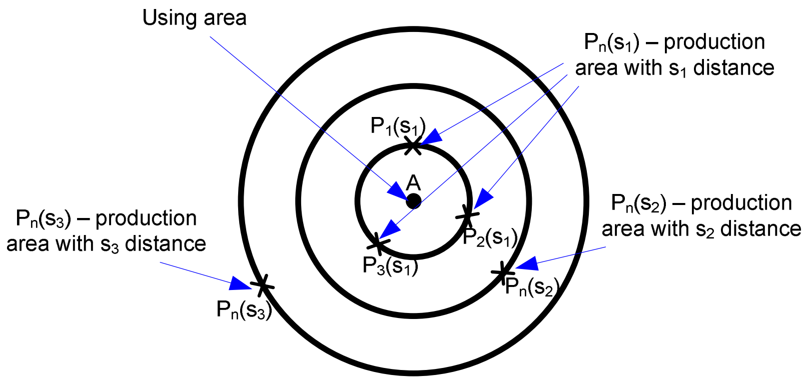


Figure 4. The locations of the possible production area

From the production areas located on the same distance the one with the least production cost is assigned to each s distance and the other areas are disregarded. So it can be formed the cost of application value function with the independent variable *s*, because only one production cost is assigned to every s distance.

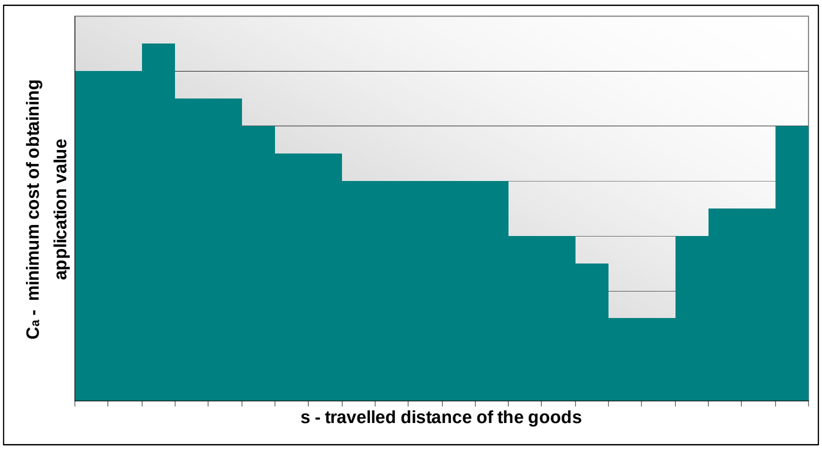


Figure5. Relationship between the travelled distance and the application value

So the summarized cost function of value added process:

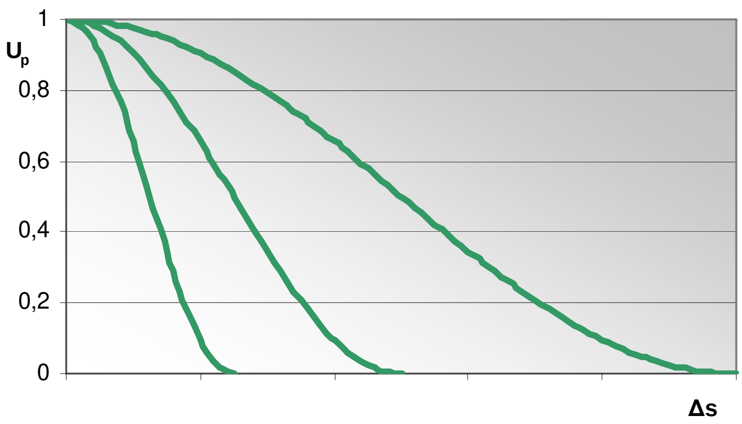
$$C(s) = C_p(s) + C_t(s) + C_a(s) \tag{8}$$

The minimum of this function determines under which conditions a product can be sent to the consumer in the lowest cost.

4. Integration of the cost function to consumer satisfaction

As previously mentioned, many consumers are willing to decrease the utility of the purchase if the cost of the purchase is decreasing also, so the optimal solution of the service can be determined only with the simultaneous analysis of the cost and the utility functions. This chapter shows the influence of utility values decreasing on the cost functions.

The cost function of the place value adjusted with the utility factor of consumer



1. Figure Possible utility values

The diagram shows that the utility of a consumer decreases steadily as the using area gets further from the purchasing area. The rate of decrease can be different by certain consumers and products.

The (9) relationship represents the steadily decrease till 0.

$$U_p(\Delta s) = \begin{Bmatrix} 0{,}5 + \cos\dfrac{\Delta s * \pi}{s_{max}} & \Rightarrow 0 < \Delta s < s_{max} \\ 0 & \Rightarrow s_{max} < \Delta s \end{Bmatrix} \tag{9}$$

Where:

Δs the distance between the place of purchase and the place of use

s_{max} the maximum distance between the place of purchase and the place of use where the product has worth for the consumer

The *Δs* variable inserted into (2) cost-function:

$$C_p(s;\Delta s) = C_{p0} + \alpha_p * (s - \Delta s)^{\beta p} \qquad (10)$$

Where: if $s < \Delta s$ than $(s - \Delta s) = 0$

The (10) formula inverted to *Δs* results $\Delta s(C_p;s)$ function, which inserted into (9) results $U_p(C_p;s)$ function

The cost function of the time value adjusted with the utility factor of consumer

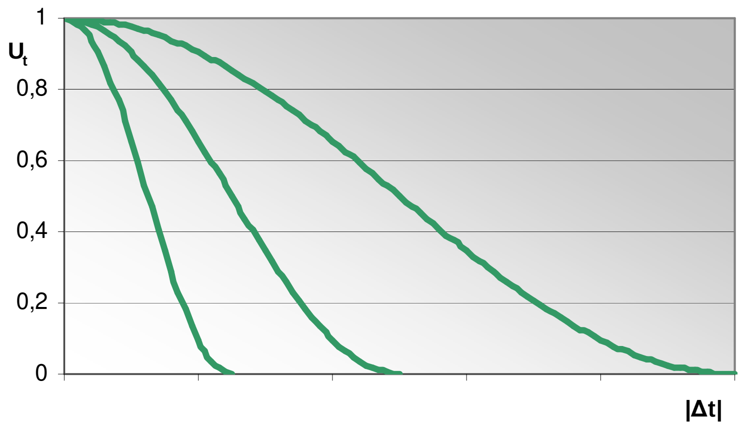


Figure 7. Possible utility values

The diagram shows that the utility of consumer decreases steadily as the elapsed time is rising between the actual and the desired moment of use. The rate of decrease can be different by certain consumers and products.

The (11) relationship represents the steadily decrease till reaches 0.

$$U_t(\Delta t) = \begin{cases} 0{,}5 + \cos\dfrac{|\Delta t| * \pi}{|t_{max}|} & \Rightarrow 0 < |\Delta t| < |t_{max}| \\ 0 & \Rightarrow |t_{max}| < |\Delta t| \end{cases} \qquad (11)$$

Where:

Δt elapsed time between the using and the demanded moment

t_{max} maximum elapsed time between the using and the demanded moment where the product has worth for the consumer

The *Δt* variable inserted into (3) cost-function:

$$C_t(t) = C_{t0} + \alpha_t * \left|t - \Delta t\right|^{\beta t} \tag{12}$$

The (11) formula inverted to *Δt* results $\Delta t(C_t; t)$ function, which inserted into (11) results $U_t(C_t; t)$ function.

<u>Summarized adjusted cost-utility function</u>

This model does not examine the decreasing utility of the application value connected to the distance and time, so leaving them unchanged the function with the adjusted cost functions can be

$$C(s; \Delta s) = C_p(s; \Delta s) + C_t(s; \Delta s) + C_a(s) \tag{13}$$

This article does not examine the relationship representing the utility of the application value, I consider it for the time being independent from distance and time, so the summarized adjusted cost-utility function will be:

$$U_{termel\H{o}}(C; s; t) = U_p(C_p; s) \cdot U_t(C_t; t) * U_a \tag{14}$$

5. Future research

This model only slightly mentions the relationship between the distance of the place of production and the place of use and the time between the desired and actual moment of use with the speed of goods forwarding. The exact definition will be discussed in later papers. The further prerequisite of the model is not only the examination of the utilities of the production side but of the consumer side also. Fuzzy-numbers are for the examination of place value and time value utilities the suitable. That method requires further research.

If the above mentioned ideas are developed the model will be suitable for determining product and consumer groups where the direction of distribution model evolution can be defined.

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Logistics Focused Cluster Analysis of Hungarian SMEs

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Abstract In this article we present the results of a cluster analysis of SMEs which was a part of a research focused on the development of logistics function along the company lifecycle. The clustering was based on logistics characteristics and stage of company growth that give the internal and external environment for logistics function. We identified four different types of companies: „Not logistics-intensive", „Improved", „Efficient" and „Inefficient", and summarized their management and logistics characteristics. We also assessed the focus and most important tasks of logistics strategy in each group.

Keywords: logistics organization, contingency theory, organizational growth, cluster analysis

1. Introduction

In this paper we present the results of the final section of our research started in 2008. The research is focused on the development of logistics organization in Hungarian companies and its relationship with corporate growth. The research involved 100 Hungarian companies operating in the sectors of manufacturing and commerce, where logistics has the most relevance. In the initial phase of the research we identified the actual phase of growth for each company using fuzzy method [15]. In the second phase we analysed the characteristics of enterprise logistics in each phase. In the third phase we extended the analysis to the environmental effects on enterprise logistics function. In this phase we focused on small and medium sized enterprises, at which size the evolution of logistics function passes off.

According to our hypothesis the SMEs can be grouped by their development and logistical characteristics. The role, value added and ideal structure of logistics function can be identified for each group.

2. Literature review

2.1. The environment of enterprise logistics

Since our aim is to analyse logistics function and its relationship to several factors, the theoretical basis of the research is given by contingency theory. Authors of this topic agree that an organizational structure is effective only if it is in harmony with its external and internal environment, and supports corporate strategy [1] [9] [11] [17]. Elements of the environment are defined and grouped differently by the authors. Kieser defined internal and external situation [11]. For Hungarian researchers, Kádárné grouped the factors affecting growth as micro- and macroenvironment [10], while Antal says that an organization can be adequate (to the company characteristics and strategy) and consistent (with the inner logic of the model) [1].

Unlike the authors above our scope of analysis is not the whole company organization but only one part: the logistics function. This makes necessary to give new interpretation of internal and external environment. Obviously, the external environment of the company is still external for the logistics function. But some factors of the internal environment, like phase of development, product range or information technology become external since they can not be influenced by the logistics organization.

As the scope is narrowed, new inter-organizational relationships come in the focus. These connections are between logistics and other corporate functions, or between logistics and the company as a whole. Gimenez and Ventura examined the relationship between logistics, marketing and production and found that cooperation positively correlate with good logistics performance [5]. Pagell extended his study also on purchasing [16], while Matyusz involved research and development in his study [14].

2.2. Enterprise logistics and corporate growth

Researchers of corporate lifecycle (Greiner1972, Churchill-Lewis 1983, Quinn-Cameron 1983, Miller-Friesen 1984, Baird-Meshoulam 1988, Kazanjian 1988, Timmons 1990, Milliman et.al. 1991, Adizes 1992, Hurst 1995) independently of the type of their growth model state that being aware of their own company's actual phase of growth give advantage to the managers. For this reason, organizational growth based studies have been carried out in the recent years in several countries, for example Russia [19], Spain [9], New-Zealand [4] and Hungary [18]. The benefit of growth models is that managers can realize the cause of problems and prepare consciously for the inevitable changes [2] [8] [13]. According to out hypothesis this applies also for logistics organizations.

Our intention was to include corporate growth as an environmental factor in our analysis. For practical reasons we chose one existing lifecycle model for this purpose. The selection criteria were the structure and the scope of the models. Regarding structure we preferred open-ended models where decline of the company is not necessary. For the scope of the models we preferred the ones that apply for all size of companies instead of the ones that focus only on early stages of life. The model that satisfied both criteria was Larry E. Greiner's lifecycle model that defines five stages, all split into an evolutionary and a revolutionary phase. The stages are the following (hereafter we refer to each stage as shown in brackets): Creativity phase (1P), Leadership crisis (1C), Direction phase (2P), Autonomy crisis (2C), Delegation phase (3P), Control crisis (3C), Coordination phase (4P), Red tape crisis (4C), Collaboration phase (5P), Internal growth crisis (5C), Alliances phase (6P), Identity crisis (6C)[6]

Several researchers of logistics management studied the way logistics organizations develop (Lambert et. al. 1998, Bowersox et. al. 2002, Frazelle 2002, Rushton et. al. 2006). The most detailed process was given by Bowersox et. al. who defines the following phases [3]:

Phase 0. Fragmented functional structures	Logistics activities are dispersed to Marketing, Manufacturing and Finance functions.
Phase 1. Functional aggregation 1	Grouping the logistical activities within the original function.
Phase 2. Functional aggregation 2	Logistics as a separated function appears with own authority and responsibility. Involves physical distribution and material management
Phase 3. Functional aggregation 3	The aim is to integrate all possible logistical activities within a single functional unit and exploit synergies. It includes planning and operations.
Phase 4. Process integration	Process organization or matrix.
Phase 5. Virtuality and organizational transparency	Logistics operations are dispersed to different functions or processes under the coordination of a CLO. Advanced IT systems provide coordination.

In our opinion these stages of logistics development corresponds with the stages of company development. In new, small and not logistics-intensive companies (as the ones in the Creativity or Leadership stage) logistical activities are dispersed in the organization, often performed together with other tasks by the same employee. As the company grows, logistical activities are more consciously organized, and there is a growing need for efficient and transparent operations. This forces companies to step into the phases of functional aggregation 1 and 2, typically when the company is in the stage of Direction.

Full functional integration (Phase 3) is reached by large or very consciously managed middle-sized companies, where the logistics function is fully developed and tasks are cleared. This is usually in the Delegation phase or later. Process integration is the solution when companies aim to rationalize their operations and focus on supply chain partnerships typically in the phase of Coordination. Virtual organizations are applied by few companies so far, but it can be a good solution for the challenges of the Collaboration phase [15].

3. Methodology

For testing our hypothesis we performed cluster analysis on the sample of 100 Hungarian companies. This method is suitable to split up the heterogeneous sample into groups that are homogeneous but differs from each other significantly. The basis of grouping is not known in advance but can be determined by analysing the characteristics of each cluster [12].

I involved in the cluster analysis only the companies that belonged to the first four stages of lifecycle (1P, 1C, 2P or 2C). The reason for this was that logistics organization appears in one of these early stages. All companies belonging to stages 4P/C or 5P/C already have developed logistics function, in several cases on a high level of functional aggregation. The formation of logistics organization can not be examined on these companies.

Besides stage of lifecycle we involved the following variables in the analysis:

Table 1. Variables of the cluster analysis (Source: own table)

Variable	***Explanation***
Age	years
Net revenue	billion HUF, for 2008
Number of employees	average for 2008
Number of employees with logistics tasks	average for 2008
Change in number of employees with logistics tasks	between 2004 and 2008
Cost of own logistics activities	percentage of total cost
Total cost of logistics	percentage of total cost
Number of performed logistics activities	out of listed activities (23 for manufacturers and 20 for commercial companies)
Number of measured logistics activities	out of 15 listed activities
Number of planned logistics activities	out of 15 listed activities
Phase of growth	1P=1; 1C=2; 2P=3; 2C=4

We performed the cluster-analysis using squared Euclidean distance for measuring similarities (default distance measure in statistical softwares). For clustering we used Ward algorithm because it guarantees that the resulting groups are as homogeneous as possible [7]. The result of the first analysis is shown on Figure 1.

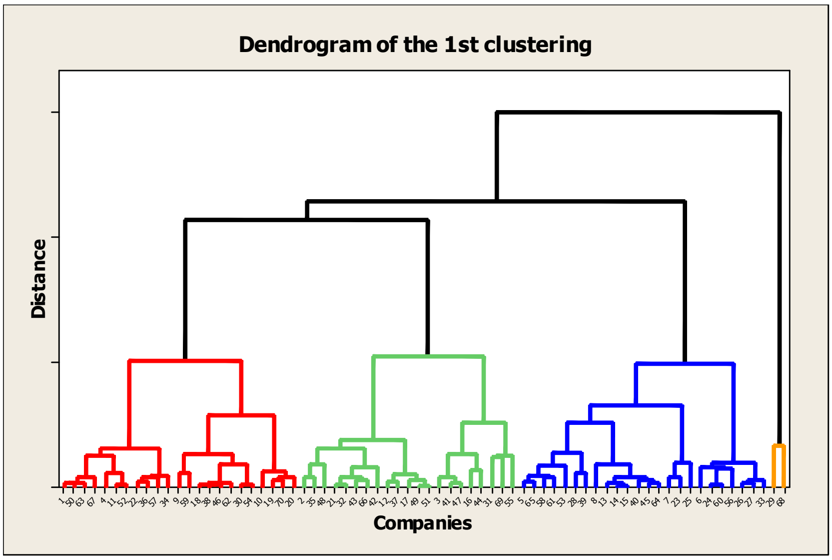

Figure 1. Result of the first clustering (Authors)

The dendrogram shows clearly that two members differ very much from the rest of the sample. We have taken out these two companies of the sample and repeated the clustering. The second dendrogram is shown on Figure 2.

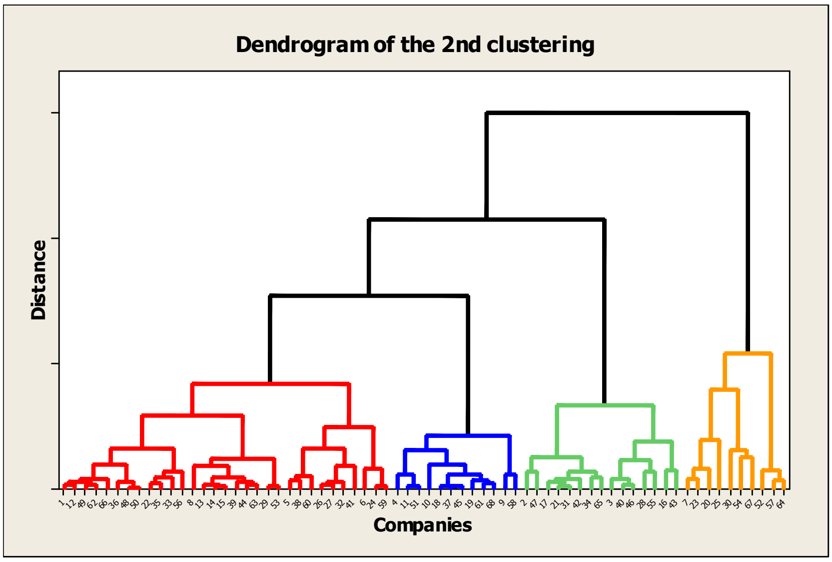

Figure 2. Result of the second clustering (Authors)

As the dendrogram shows, the sample can be divided to four clusters. Cluster 1 includes 31 companies, Cluster 2 15, Cluster 3 12 and Cluster 4 10 companies. Table 2 shows the averages and standard deviations of the variables involved in the analysis.

Table 2. Averages and standard deviations of the involved variables (Authors)

Cluster	1		2		3		4	
Variable	***avg.***	***st. dev.***	***avg.***	***st. dev.***	***avg.***	***st. dev.***	***avg.***	***st. dev.***
Age (yrs)	11,13	5,89	14,58	4,01	10,33	5,90	12,60	5,52
Net revenue (billion HUF)	0,94	0,94	0,48	0,29	0,83	0,78	3,87	2,74
Number of employees	26,48	17,98	18,67	5,77	30,07	20,30	135,40	104,52
Number of employees with logistics tasks	2,65	1,33	2,58	1,38	3,53	2,53	12,60	6,87
Change in number of employees with logistics tasks	32,10	44,28	8,89	44,82	30,34	41,60	30,33	40,76
Cost of own logistics activities (%)	2,55	0,81	2,33	0,65	5,33	0,72	2,90	1,52
Total cost of logistics (%)	2,97	0,87	2,67	0,78	5,67	0,49	3,40	1,51
Number of performed logistics activities	20,97	1,85	16,50	3,45	19,20	2,76	19,10	2,56
Number of measured logistics activities	9,55	2,19	6,00	2,49	8,93	2,09	10,90	1,60
Number of planned logistics activities	7,58	3,03	3,75	2,30	6,13	3,60	8,20	2,44
Phase of growth	2,29	1,01	1,42	0,51	2,00	1,20	3,20	0,79

We have tested all variables for significance in the model using analysis of variance. Two variables: „Age” and „Change in number of employees with logistics tasks” did not show significant difference across the clusters.

4. Findings

4.1. Clusters

The four clusters differ in their stage of development and logistical characteristics. We assessed the characteristics of each cluster as follows:

Cluster 2 – Small, not logistics-intensive companies („Not logistics-intensive")

The smallest, least developed companies belong to this cluster. Their logistics organization has not developed yet, due to small importance of logistics. These companies perform measure and plan significantly less logistics activities than the others. The growth of logistics staff is slower than in other clusters but this difference is not significant due to large standard deviations. Logistics is not considered as a strategically important field that has to be improved.

Cluster 4 – Medium-size companies with improved logistics („Improved")

These are the largest companies regarding both revenue and number of employees. These are also the most developed ones (stages 2P or 2C). The number of employees with logistics tasks is far higher than in the other clusters, which presumes the existence of logistics function. Large number of measured and planned logistics activities supports this presumption.

Cluster 1 – Small companies with efficient logistics („Efficient")

This group is on half way between the first two regarding size and development. The number of employees with logistics tasks is relatively low but they perform significantly more tasks than the ones in Cluster 2. The level of logistic costs is low, which suggests that logistics is organized efficiently.

Cluster 3 – Small companies with inefficient logistics („Inefficient")

This group is very similar to Cluster 1, the only difference is in the level of logistic costs, which is significantly higher in this cluster. Since the number of employees and the number of tasks performed in not larger than in Cluster 1, we assume that logistics processes are less efficiently organized. The heterogeneity of field of activity in both clusters supports this assumption.

4.2. Logistics and management characteristics of the clusters

The „Improved" is the cluster that differs the most from the other clusters. This is because its members have reached a higher level of development both in management and logistics. The other three clusters have more similarities in age and size, which makes it more interesting to compare their management and logistic characteristics, especially for the „Efficient" and the „Inefficient" group. These two clusters represent the companies that react in time and late to the changes of the environment.

4.2.1. Management characteristics

Out of general management characteristics we examined the question of owners and managers, and the existence of conscious planning in the company. According to the literature these features have great impact on effective handling of challenges and company growth. The differences between the clusters are shown on Table 3.

Regarding the ownership questions the „Improved" cluster differs significantly from the others due to the high ratio of foreign and low ratio of private ownership. This results in higher external pressure for growth and often helps from the owner organization in the form of know-how transfer or conscious organizational development.

„Improved" companies perform better in the field of planning as well, as they have written strategy, vision and business plan in the largest ratio. These management tools are used the least often by the „Inefficient" group, which suggests that these companies are rather floating than planning their future. This hampers both growth and effective organizational work.

Table 3. Management characteristics of the clusters (Authors)

	Small, not logistics-intensive companies	***Medium-size companies with improved logistics***	***Small companies with efficient logistics***	***Small companies with inefficient logistics***
Organizational structure	Simple / Functional	Functional	Simple	Simple
Ratio of foreign ownership	8%	40%	16%	13%
Ratio of private ownership	83%	40%	74%	83%
Executive is professional manager	8%	60%	16%	13%
Has a vision	58%	60%	45%	33%
Has written strategy	50%	70%	55%	47%
Has a business plan	92%	100%	84%	73%
Has a running project	42%	60%	71%	53%

The existence of running projects indicates growth orientation, while companies without projects stagnate. From this aspect the best performers are the „Efficient" companies, while „Not logistics-intensive" and „Inefficient" clusters are the weakest ones. These companies do not realize the need for development or they are incapable of it. One of the causes can be that the presence of professional managers is the lowest in these two groups.

4.2.2. Logistics characteristics

Table 4. Logistics characteristics of the clusters (Authors)

	Small, not logistics-intensive companies	**Medium-size companies with improved logistics**	**Small companies with efficient logistics**	**Small companies with inefficient logistics**
Outsourcing (full or partly)				
Warehousing	16%	20%	32%	13%
Transportation, distribution	75%	80%	74%	67%
Other logistics	58%	30%	58%	40%
Most important requirements on logistics				
To suppliers	Rapidity Reliability Price	Price Quality Reliability	Quality Price Reliability	Quality Price Reliability
From buyers	Price Quality Reliability	Quality Price Rapidity	Price Quality Rapidity	Price Quality Reliability
On internal processes	Cost Quality Flexibility	Cost Quality Throughput time	Quality Cost Throughput time	Cost Quality Throughput time
Makes investments in logistics	33%	50%	48%	13%
Uses ERP	33%	50%	39%	13%

Outsourcing is the most common in transportation and distribution regardless of clusters. The least preferred is the outsourcing of warehousing. „Efficient" companies are leaders in outsourcing, while the file-closers are the „Inefficient" companies. Accepting that outsourcing increases service level and reduces cost, the difference in efficiency between the two groups can be partly explained by the level of logistics outsourcing.

The requirements on logistics are not significantly different across the clusters. Low price and good quality are the most important performance indicators that the buyers require. The companies demand good quality, low price and reliability from their suppliers. The result is very similar in the case of internal processes where cost substitutes price. The difference between the first two aspect is very low in each case, the other aspects follow them at a greater distance. This means that the companies succeed in converting the requirement of their buyers to internal priorities and in transferring them to their suppliers.

The number and value of investments in logistics show how important is logistics in the company strategy. From this point of view „Improved" and „Efficient" companies emerge from the sample. The „Improved" companies need more investment to stay in competition and also have more innovation possibilities because of the advanced state of logistics function. The „Effective" cluster has outstanding performance compared to the other clusters of small companies, which suggests that logistics is considered as a strategically important field. The „Ineffective" companies make the least investments, even less than the „Not logistics-intensive" group. Logistics is neglected in these companies, which prevent them from exploiting increase in service level or decrease of costs. This effect is strengthened by the lack of ERP systems in this cluster.

In the questionnaire we asked the companies to evaluate their own logistics service level from three points of view: compared to the internal requirements, to buyers' expectations and to the competitors' service level. From the first aspect most companies (80-90%) consider their performance adequate, except for the „Inefficient" cluster, which is more heterogeneous: 20-20% considers the service level better and worse than the required respectively. Regardless to the clusters, a reasonable number of companies declare that their performance is better than the buyers' expectations, which suggests that the internal requirements are stricter than the buyers' expectations.

The companies also had to evaluate the level of logistics costs. In the „Inefficient" cluster half of the companies answered that their cost is higher than expected, while in the other two clusters of small companies this ratio is notably lower (29 and 25%), and stays under 10% in the „Improved" cluster. All clusters considered their costs lower than the competitors, assuming that the cost-increasing effects apply to them at least at the same way.

5. Conclusion

5.1. Conclusions on the variables involved in clustering

Some of the variables did not show significant difference across the clusters. These were „Age" and „Change in number of employees with logistics tasks". These variables can be omitted from further analyses.

Two variables: „Cost of own logistics activities" and „Total cost of logistics" show strong correlation, and for this, one of them can be eliminated. Since, according to the questionnaire, outsourcing did not play an important role among SMEs, we suggest the elimination of „Cost of own logistics activities".

5.2. Significance of the clusters

The use of logistics-based clusters of SMEs is that typical logistics problems and suggested way of development can be outlined. This can be a basis of general concepts of development for each type of companies. The focus of logistics strategy, which predicts the importance of logistics function, the structure of logistics organization, the direction and intensity of the improving activities, is completely different in the separate clusters. Briefly, these can be the following:

- Small, not logistics-intensive companies („Not logistics-intensive")

The great majority of logistics activities are operative tasks. The aim of logistics strategy is to provide an acceptable service level to the partners, and keep the low level of costs. Moderate development is enough to keep the position on the market. From organizational aspect the ideal organization is small and effective. This needs the concentration of logistics tasks into the hands of few employees, which corresponds to the first level of functional aggregation.

- Medium-size companies with improved logistics („Improved")

For providing adequate service and cost level in this cluster, logistics needs to be managed at strategic level. The logistics function appears or already exists in their level of development, the aim is to integrate logistics activities within the boundaries of one organizational unit (functional aggregation 3). Logistics can be one of the competitive advantages and needs continuous innovation. An important task of logistics management is to find more and more efficient solutions, among others possibilities for outsourcing.

- Small companies with efficient logistics („Efficient")

The logistics system of these companies basically functions well, the function has the adequate strategical focus. The main task of logistics management is the continuous monitoring of performance indicators and costs, and intervention in case of negative tendencies. This phenomenon is expected to occur as the company grows.

- Small companies with inefficient logistics („Inefficient")

Logistics system does not function ina n optimal way, because costs are high with no outstanding performance in service level. Logistics has a remarkable cost-reducing potential. The task of logistics management is to revalue the importance of logistics, and raise it onto strategical level. Rationalization of processes and organization and reduction of costs is essential to increase efficiency.

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Efficiency in Transport Logistics: an Academic and a Practical Viewpoint

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Abstract The present article aims to define the term efficiency in the field of transport logistics. First the definitions to be found in the literature are scrutinized. An attempt is made to distinguish efficiency from effectiveness, performance and cost-effectiveness and to determine how they are interrelated with each other. Then, in the second part of the paper the practical side of efficiency is researched by examining a number of projects dealing with some aspect of transport logistics, trying to capture the characteristics that could contribute to efficiency. These features are found to be the application of telematics, the dissemination of information and improvement of management, the intermodality, the invention of new techniques and technologies and the presence of sustainability.

Keywords: efficiency, transport logistics, projects

1. Introduction

Evaluation of logistic systems is becoming more and more important, and efficiency is mentioned frequently, but what do we exactly mean by efficiency? How can we distinguish it from effectiveness and how does it relate to the performance of the company? What projects are launched to enhance efficiency? In the next section of the paper the authors try to discern efficiency from performance and effectiveness, keeping in mind the area of application, that is, transport logistics. After having discussed efficiency from an academic aspect, the practical side is also investigated by looking into numerous projects dealing with transport logistics. Our aim is to pinpoint those major areas or common features of these projects which seem to be significant in boosting efficiency.

2. The definition of efficiency

Even only using our common sense, we can be aware that efficiency, performance, effectiveness and cost-effectiveness are all terms closely interrelated with each other. In order to give the most appropriate definition of efficiency we have to start with looking at performance.

2.1. Performance

Due to its all-encompassing nature and extreme popularity, it is very difficult to find a single definition of performance [10], and indeed few authors give an explicit definition for performance but treat it as an axiom [23]. Webster's New World College Dictionary defines performance as "1) the act of performing; execution, accomplishment, fulfilment, etc. 2) operation or functioning, usually with regard to effectiveness, as of a machine 3) something done or performed; deed or feat 4) a) a formal exhibition of presentation before an audience, as a play, musical program, etc.; show b) one's part in this" [17]. The Dictionary of the Hungarian Language has a slightly different emphasis. First, there is no reference to the meaning listed in the Webster Dictionary under 4), as in the Hungarian language "performance" as translated to "teljesítmény" lacks this meaning. Then, the definition goes as follows: "the quantifiable, data-like result which can be reached by someone or something in the course of work or other professional activity in a given timeframe." (Dictionary of the Hungarian Language) Very significant part of the definition is the "data-like" nature of the result, which is characterised by different authors in a different way.

According to Leigh "only that can be considered as the performance of a company which contributes to the improvement of value/cost ratio", while Kaplan and Norton [13] regard performance as a merely financial category, and try to capture the "data-like" result referred to above by applying different financial indicators. Another aspect of performance is highlighted by Otley [19], who defines the notion as the effective realization of the aims of a company. This approach is reflected by Adams and Kennery [1] as well, where the above mentioned aim is also given: "the aim of the organisations is to serve the consumers more effectively and efficiently than its rivals do". Thus performance is characterised by effectiveness and efficiency. This view is shared by Chikán and Demeter [5] also, who quantify performance using effectiveness and efficiency.

Kaplan and Atkinson [12] determines three dimensions of performance: service, quality and cost; and then creates key performance indicators according to these dimensions which can help verify whether the performance reaches the expected standards. Whereas Folan et al [10] determine the three governing objectives of performance as the following: the action carried out must be 1) standardized, non-random 2) quantifiable and 3) it must retain a relevance to the performer. So again we see that the quantifiable, data-like character of performance emerges. Domonkos [7] identifies 7 dimensions of performance: effectiveness, efficiency, quality, productivity, labour quality, innovation and profitability. The most widespread view, however, sees performance as a result of only four components: cost-effectiveness, effectiveness, productivity and efficiency

[24]. From all the definitions above it seems to be clear that efficiency is one dimension of performance and this is where we want to proceed from in the next subsection.

2.2. Efficiency

Having established that efficiency is one dimension of performance we can go further by looking at this notion through the work of different authors. According to Marosi [15] "that organisation can be regarded as efficient which can achieve its aims successfully with a satisfying, or acceptable ratio of costs and results (or generally speaking, inputs and outputs)." The same idea can be detected in the work of Dobák [6] who says that "efficiency is the capability of a company to realise its stated objectives, and to use its available resources cost-effectively." Webster's Dictionary also defines efficiency in a similar way, according to which efficiency is "1) the ability to produce a desired effect, product, etc. with a minimum of effort, expense or waste; a quality or fact of being efficient 2) the ratio of effective work to the energy expended in producing it, as of a machine; output divided by input" [17]. The same view is shared by Borotvás et al[4] when they discuss that the essence of economic efficiency is whether certain investments can under the given circumstances provide for the best utilization of the resources.

The definitions cited above indicate clearly the two-sidedness of the notion efficiency. First, it can be viewed as a ratio, or even just as a relationship, between the inputs and outputs of a company. In this case efficiency is a quality of performance that can vary in a continuous (i.e. non-discrete) way and the stated objectives of the organisation are not necessarily present in the definition. This approach to efficiency is also mirrored by Drechsler [8] and Román [20], and to some extent by Kaplan and Norton [13] and Győriványi [11]. On the other hand, a company can be viewed as efficient when it can reach its predetermined objectives, when it can create the desired effect. This approach is seldom utilised without the other; nonetheless, the Dictionary of the Hungarian Language defines efficiency by "effectiveness", i.e. power to produce effects or intended results (Dictionary of the Hungarian Language).

Keeping in mind the definitions and usage of the term efficiency in the literature cited above, efficiency can be defined as follows: "The ratio of the products, services and other results produced during a given activity and the resources utilised for their production." This definition has several advantages: with its help efficiency can be objectively measured by mathematical applications, for example data envelopment analysis (DEA) and it can easily be adapted to transport logistics[23] Thus, according to the authors of the present paper efficiency in transport logistics shall be defined in the following way: "The ratio of the services and other results produced by the logistics firm and the resources utilised for this production." The authors believe that this ratio describes well that non-discrete feature of performance that we generally understand under efficiency.

2.3. Effectiveness, cost-effectiveness and productivity

In order to see clearly in the cobweb of notions surrounding performance and to distinguish them form efficiency, the authors wish to define three further concepts, the other dimensions of performance: effectiveness, cost-effectiveness and productivity. It is of utmost importance to define effectiveness, as it seems to be the counterpart of efficiency, and it is also often intertwined with it. In our view effectiveness determines how the given organisation can reach its predefined goals, i.e. this is the "other side" of efficiency. It has nothing to do with inputs, it only shows how the outputs, that is the results, match the predetermined objectives[23] This is approach is also backed up by Bauer and Berács [3] and also by Osborne and Gaebler [18]. As Webster's Dictionary also states, effective "is applied to that which produces a definite effect or result" [17]. Consequently, effective is a company in the field of transport logistics if it can reach its predefined goals.

Cost-effectiveness, on the other hand, deals with inputs: it shows how economically the available resources have been utilised during the given activity[23] According to Webster's Dictionary cost-effective means "producing good results for the amount of money spent; efficient or economical" [17]. As we have been able to see, in the common language these notions are often explained with each other, however, it is vital that in the scientific field they are properly distinguished from each other. Thus we can say that a logistics firm is cost-effective if it utilises its resources economically for the production of its services.

Productivity shall also be connected to the input side of the production process, as it emphasizes how much input is needed for the production of one unity of output. Its most popular form is labour productivity, which expresses the amount of labour required for the production of output [4]. Figure 1. illustrates the difference between the different dimensions of performance.

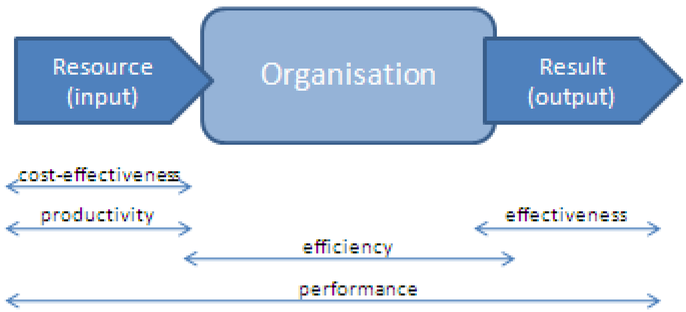

Figure 1. The place of "efficiency" within the different dimensions of performance (Source: own edition as based on [23] and own research)

3. Projects contributing to efficiency

Having defined efficiency and its peer-notions, the authors of this paper reviewed a number of European level and national research projects with the sole objective in mind of pinpointing the factors that can or could contribute to efficiency when applying the results of these research works. Being perfectly aware that such a summary could never be complete, some themes have however emerged as fields which seem to be significant in efficiency enhancement. The application of telematics, dissemination of information and improvement of management, intermodality, invention of new techniques and technologies, the presence of sustainability are the sometimes overlapping fields around which the majority of projects can be clustered. While highlighting the different areas we were intent on giving examples which illustrate best the significance of the given theme, although the same project could be important in a different field as well.

One part of current national and European level projects have the aim of making a greater use of the possibilities lying in modern telematic systems. These contribute to efficiency through better localisation (tracking and tracing) of the vehicles or even the freight being transported. The most significant European research projects relevant to this field have various goals: creating a common and harmonised tracking and tracing in the road and railway sector (CESAR II), tracking and tracing on parcel level in the same transport modes using RFID (ParcelCall), surveillance and protection of the goods in the road sector (ASAP), enabling the transportation of the goods in a transport crate equipped with RFID (iBoS), creation of a virtual fleet for the small haulage companies to make them more competitive (TROP), port organisation, better navigation, sustainability (EFFORTS), the creation of a freight transport monitoring system and a transport chain management system for intermodal chains (D2D), use of freight information in the railway environment (FIRE), monitoring cross border train movement in real time (BRAVO), offering one-stop-shop freight managements for SMEs (GIFTS) and rail car asset management (F-MAN). Thus one element of efficiency could be that of the use of telematic systems which provide the companies with more reliable information on the place (and recently sometimes even the state) of the goods.

Another dimension of efficiency is the availability of information needed for more efficient operations. There are a number of projects which deal with the dissemination of information and with the efficient tools of information. Examples include projects with the aim of creation and dissemination of logistics best practice (BESTLOG), of dissemination of information (CENTRAL LOCO), of making available information and communication tools for secure and efficient information exchange in intermodal chains (SESTANTE), of managing and integrating information on the inland waterways (IP), of creating a global integrated transport logistics data network for intermodal chains (GILDANET). A closely related field is that of the enhancement of management, which is not only achieved by higher quality information but harmonised standards as well. Projects that can be mentioned in this field aim at the creation of an improved management and information exchange (FREIGHTWISE), the harmonisation of standards (D4D) or the invention of a terminal simulation system (TRAPIST) [22], [25].

Another echelon of improving efficiency is that of intermodality, the enhancement of which has long been a priority of the European Union. In order to achieve intermodality, a number of new systems are being developed. Examples include umbrella projects covering different transport modes on European level, like the Vessel Traffic Management and Information System (VTMIS) integrating several systems, such as the Automatic Identification System (AIS) and the Long Range Identification and Tracking (LRIT systems) in maritime transport, the River Information Services (RIS) for inland waterways, the European Rail Traffic Management System (ERTMS) and the European Air Traffic Management System within SESAR (Single European Sky ATM Research) [9]. Of course, several smaller projects could also be cited as example here, but as they are in the reach of other themes as well, they are not mentioned here, but under the heading of "intermodal chains" within their given topic.

Novel techniques and technologies together with new IT solutions can also provide important steps towards more efficient transport logistics. The following European level projects invent new technical solutions and thus influence the efficiency as well: VRSHIPS-ROPAX, with the goal to examine ship technologies through the creation of a platform; BRAVO, to monitor cross border train movements in real time; FASTRCARGO, to create a new loading system in order to speed up loading/unloading at the railways; CARGOSPEED, to accelerate cargo and rail interchange, INTEGRATION, for integrated and improved ship-shore systems, INTERGAUGE, to create a new freight movement technology for railways and ISTU to invent an integrated standard transport unit for self-guided freight-container transportation systems on rail [22].

Table 1. Examples from the different fields (source: own edition)

	Road transport	**Rail transport**	**Inland waterways**	**Ports and/ or maritime transport**	**Intermodal chains**
Telematics	CESAR II	CESAR II		EFFORTS	D2D
	ParcelCall	ParcelCall			
	ASAP	FIRE			
	iBoS	BRAVO			
	TROP	F-MAN			
	GIFTS				
Information and management	BESTLOG	BESTLOG	BESTLOG	BESTLOG	BESTLOG
	CENTRAL LOCO	CENTRAL LOCO	CENTRAL LOCO	CENTRAL LOCO	CENTRAL LOCO
			IP	TRAPIST	SESTANTE
	FREIGHTWISE	FREIGHTWISE	FREIGHTWISE	FREIGHTWISE	FREIGHTWISE
			D4D		GILDANET
Inter-modality		ERTMS	RIS	VTMIS (AIS, LRIT, etc.)	not applicable
New technology		BRAVO FASTRCARGO CARGOSPEED		VRSHIPS-ROPAX	
	INTEGRATION			INTEGRATION	INTEGRATION
		INTERGAUGE			
		ISTU			

Finally, paying attention to sustainability and external costs can also pave the way for more efficient operations especially now that the pressure is getting bigger on companies to incorporate these aspects into their management. Operating in a sustainable way can also amount to comparative benefit. Environmental awareness is in the focal point of more and more research studies [14]. Two, separate projects have dealt with this aspect of transport logistics as well. A Hungarian research project looked into the evaluation of transport alternatives from the point of view of sustainability, meaning that economic, environmental and social factors were taken into account with the same weights. Using a multitude of indexes the Simongáti introduced a model covering all these three features, calculated the SPI (Sustainable Performance Index), and showed how sustainability can easily be included into the managerial decisions [21]. A European level research project, RECORDIT aimed to help in the calculation of internal and external costs of intermodal transport thus propagating the choice of this transport model [22].

The present article has set the aim of defining the different notions clustering around efficiency in transport logistics. The authors have shown that next to effectiveness, cost-effectiveness and productivity, efficiency is one dimension of performance. Then the definition of efficiency in transport logistics for scientific purposes has been provided as the following: "The ratio of the services and other results produced by the logistics firm and the resources utilised for this production." It has been noted that this definition is particularly appropriate for the mathematical evaluation of efficiency. It has been shown that effectiveness is a peer-notion, and an organisation in transport logistics can be seen as effective if it can reach its predefined goals.

Then, reviewing numerous projects in the field of freight transport and transport logistics it has been identified that the application of telematics, the dissemination of information and improvement of management, the intermodality, the invention of new techniques and technologies and the presence of sustainability are the main areas around which the majority of efficiency boosting projects cluster. Future research work will include the evaluation of logistics organisations using the definition of efficiency delivered above, with special attention to the EU level and other projects which can contribute to their efficiency.

4. Acknowledgement

This work is connected to the scientific program of the "Development of quality-oriented and harmonized R+D+I strategy and functional model at BME" project. This project is supported by the New Hungary Development Plan (Project ID: TÁMOP-4.2.1/B-09/1/KMR-2010-0002).

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A Hierarchical Model to Evaluate Public Transport's Supply Quality

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Abstract There are several elements of supply quality in public transportation. These elements are often referred, but only some of them are mentioned at a time, and regularly some confusion can be discovered in this topic. In order to get a clear and complex image, we constructed a hierarchical model to elaborate all elements of a public transport system. This model has been tested on a Japanese city's bus transport system. The gained results are introduced shortly in the paper.

Keywords: hierarchical structure, AHP (Analytic Hierarchy Process), supply quality elements

1. Introduction

In many countries in the world, the low utilization of public vehicles is a crucial problem. There are many disadvantages of this phenomenon, such as heavy traffic on the roads, increasing number of accidents, CO2 emission, parking problems, declining revenues for the public transport companies. While the costs of these companies are increasing, the loss is growing simultaneously, and the government has to spend much for financing this debt.

So for the government (and for the public transport company as well) the aim is to motivate people shifting from cars to buses, trams and other public vehicles.

One way of the motivation can be easily determined: to cut fares, but as mentioned above, there has been already huge loss for the public transport companies, and – at least in a short-run – this measure would increase this loss. On the other hand, the revision of costs may be a useful tool for the public companies [1].

Apparently there is only one way left to increase the utilization: to raise the supply quality of public transportation.

For this, the following steps are advisable to take:

- Decrease the dissatisfaction of passengers and non-passengers.

- Make public transport more attractive for non-passengers.
- Consider all 3 participants' (passengers, company, government) aspect [7].
- Synchronize different objectives (getting high service level, run effectively, maintain service level while restrict spending).

Integrating the mentioned criteria, we constructed a hierarchical model that can be used for the evaluation and analysis of all elements of public transportation. This specific model has been made for the elaboration of a city's public bus transport system, but with some minor modification, it can be extended for every kind of public transport.

2. The structure of the model

The model can be considered not only for static analysis of the certain system, but also for a dynamic evaluation that is able to highlight directly the sensitive points and may hint for necessary developments [4].

Another advantage is that all 3 participants can make judgments of the elements so the results are comparable [8] and the differences can be easily determined.

For the static analysis, a simple questionnaire can be applied, e.g. the evaluators should give points from 1 to 10 for the different elements (minding the hierarchy!). By this, we get a clear picture, how satisfied they are with the segments of public transport.

For the dynamic analysis, the necessity of development should be asked by the questionnaire. E.g.: How important is it from your point of view to develop this element of public supply?

The necessity of development embodies the importance of the element and the satisfaction level as well [5].

The constructed model is shown in Figure 1.:

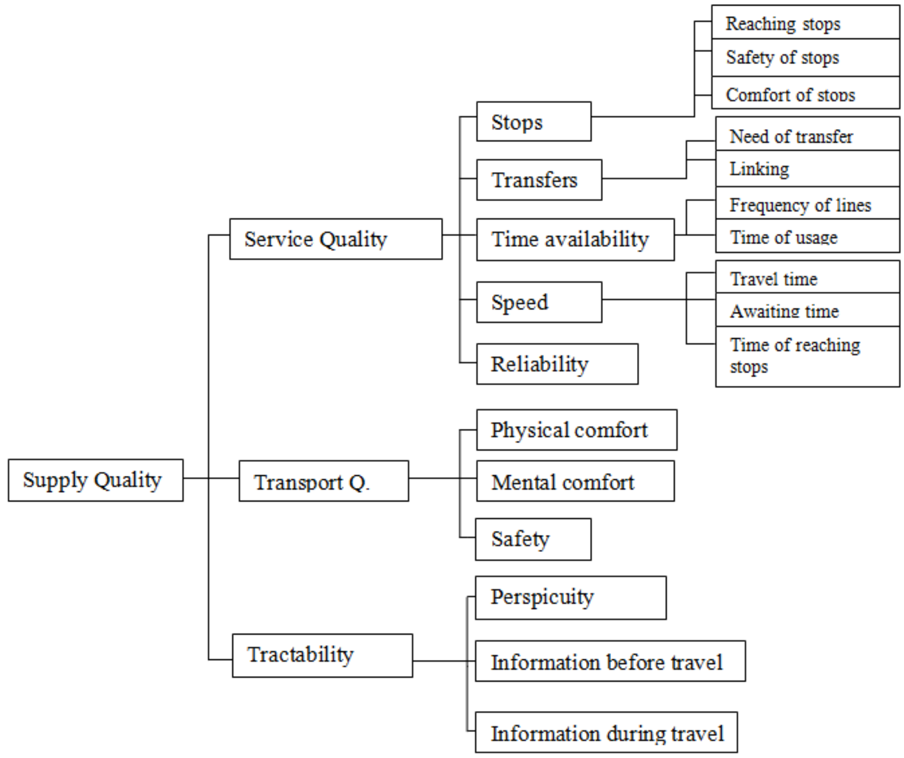

Figure1. The Hierarchical Structure of Public Bus Transport (Source: own exhibition)

Maybe the segment of "mental quality" should be explained in detail. We integrated all issues in this element that reflect the mental feelings of the passenger during the journey, such as the politeness of the driver, the image inside the vehicle, and so on.

We have tested this model on a Japanes city's (Yurihonjo) bus transportation system and got some very promising results. From company managers and governmental officials no remarks had been received that the model should have been amended or some elements should have been left out. There were some points (e.g. the frequency of lines and perspicuity) that showed totally different opinions from the passenger side and the governmental/company side.

3. Results of a preliminary study

A previous study was made to evaluate the situation of Yurihonjo's bus transport. The characteristics were the followings:

- 29.556 evaluators were asked out of the total population of 50.000, so the preliminary survey can be regarded as representative.

- It was made by a consultant company, so it included only statistical analysis and did not use more complex methodology.
- The survey was made in March, 2010, so it contained fresh and relevant information.
- Only the passenger side was asked.
- Reasons of dissatisfaction with public bus transport mentioned were:
  1. Bad time availability. (Not convenient frequency of lines) 64%
  2. Fare is too high 27%
  3. Long distance to and from stops 26%
  4. Connection to train not convenient 16%
  5. Limited time of usage 12%

45% responded to use more public bus transport if the mentioned issues are improved. That means 13.500 possible new users or more time users, although it includes the claim of lower fares as well [2], not only the development of supply quality [1] [3] [4] [5].

Highlighting the crucial points of the supply and simultaneously synthesizing the 3 different aspects of the participants' point of view may help significantly to improve the utilization of public vehicles.

4. Results of the test phase of the constructed model

The characteristics of the conducted survey based on the hierarchical model were the followings:

- 30 university students, 9 office workers and 2 research experts (who were involved in the previous survey, so had enormous information about passengers' opinion) were asked for the passenger side
- 3 company managers and 3 government officials (in the relevant field) were asked for the company and for the government side
- The survey was made in June, 2010, and analyzed in July 2010.
- Questionnaires were made for the evaluation that contained questions based on the hierarchy (Figure 1.). For the static elaboration the element had to be evaluated in a scale of 1-10, 1 was absolutely dissatisfied, 10 was absolutely satisfied. For the dynamic elaboration, the Analytic Hierarchy Process (AHP) was applied [6]. Because of this, pairweise comparisons had to be made by the evaluators for all the elements of the model, considering the hierarchy levels. For the 1.st level the following questions were asked: "Compare the importance of improvement for the service quality and transport quality element of the model! Compare the importance of improvement for the service quality and tractability elements! Compare the importance of improvement for the transport quality and tractability elements!" For the 2nd, and 3rd level the

same structure was constructed. In order to simplify and reduce the number of questions we applied matrices to embody the pairweise comparisons.

- During the AHP process we examined the consistency of answers, so applied a filter [2] to analyze only the logical and consequent answers of the evaluators.

By this process, the gained results are the followings:

The passenger side mentioned the greatest need of improvement in the segment of service quality. The tractability got in the second place and the transport quality development is not significant at all for the public bus users. On the contrary, government and company side evaluated transport quality as the most important issue to improve. This result shows the very common problem of public transport, company managers think that the most important way of getting more passengers is to change the vehicles to new ones. The gained results show the opposite, government and company experts should concentrate on the elements of service quality.

For the 2nd level, users mentioned the stops and transfers as the two most sensitive points of the system. Company managers seemed to realize these claims; although they mentioned the improvement of speed as well (the passengers were totally satisfied with this element). The government officers were not so aware of the users' point of view; they think that the speed is the most important for them, and the physical comfort of the journey. This issue reached the last position for the passenger's side.

For the 3rd level users mentioned the distance to and from stops as the most inevitable issue to improve. Company managers thought that the frequency of lines should be improved for the first time, and it is partly true, because in the case of some lines it was declared very clearly by the passenger evaluators. But in the case of other lines, the frequency of lines is totally satisfying for the users. That means that a thorough analysis should be made to shed light on the lines which should be more frequented by buses and the ones which should not. The government mentioned the travel time as the most crucial point, but the other sides' evaluation did not verify this.

Based on the gained results it can be stated that:

- The model is suitable to evaluate the opinions of different participants of public transport.
- The introduced hierarchy embodies all important elements of public bus transport's supply.
- There are discrepancies among the visions of public transport of different participants; users, company managers, government officials.
- These contradictions should be eliminated by synthesizing the different opinions and creating a common image on the necessary improvements.
- Specifically for the examined city: the most urgent step is to replace the stops with the consideration of passengers' claims. The most crucial point is the distance to and from stops, so this distance can be reduced by the replacing process. It may be expensive but surely will bring more users and will produce profit in the long-term. Another inevitable issue is to revise the frequency of every line and alter it in some cases.

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Competitiveness of cities, searching for a model to optimize cities

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Abstract A larger and larger proportion of the world's growing population lives in towns and cities. Cities can often be the places where work and related opportunities are available in concentrated forms. Besides the positive factors several negative externalities emerge. Cities are the drive of growth. The reason for this lies in the concentration of human knowledge in permanent human interaction, which is obviously concentrated in big cities and towns [1]. In our article besides the overview of the developments of cities and the connection of economic models we are looking for an answer to the questions, is it worth dealing with the optimal form of cities? And what kind of mathematical instruments can be used to sort the factors? Our hypothesis is: the problem can be modelled by fuzzy neural nets because they are able to integrate subjective and uncertain factors as well.

Keywords: Cities, optimization, competitiveness, fuzzy neural nets

1. Introduction

Recently, beside the analysis of the region, the successfulness of cities has been put into the centre of regional researches. It is not by chance, since a greater part of the population lives in towns and cities. „Nowadays there are more than 300 cities (city-regions) on the Earth having a population over one million, there are almost twenty among them having more than ten million inhabitants" [2]. Not only science, but also politics are looking for factors, which can help in the competition or to improve market-positions.

Cities are not optimal in itself, a closer or wider environment of the city determinates the functions of the city. Regional policy's task is to develop the optimal approximate opportunities

During the development of mankind the first farmers created bigger communities, which had its impact on population density and on special organizations as well. Trade also started at this time as well, first inside the town, but later on among towns as well. This had the social effect that isolated people got in touch with each other and the population density became concentrated in some places. We can find a lot of studies and works dealing with the evolution of towns and how they fit in the development line, which was supported by several scientific discussions. Haggett mentions 4 levels in development: primitive hunting and collecting, having herds, agriculture and urbanized way of life. They are connected to three processes: domestication of animals, growing of cereals while settling down and an urban way of life [3].

Because of the development of towns a major part of mankind is concentrated in these places. It has several advantages and disadvantages. It is not easy to typify towns and cities at all. It is the task of each country to create the legal or administrative definition for cities, but it is connected mostly to the size of its population, to its functions, and services. These are significantly different. In the process of urbanization agriculture has an important role and trade is held in high esteem. This is due to the surplus of products and in the end the urban way of life develops an important role. The developments of economic theories also show a similar path in the development process, which has an obvious connection.

2. Basic economic trends and theories about sites

As population, cities, technical development and the way of life are changing, so are the trends of economics. If we examine the economic family tree, we can see that economics is still a young field of science among the sciences. The classical school was formed by the works of Adam Smith after the physiocrats and mercantilists [4].

The physiocrats derived their theory from the order of nature and they considered agriculture as the source of national wealth. Their school was formed at the end of the 16th century in France and England. One of their main principles was that the economy is free from state intervention since its operation is predestined by God. From the 15th century the mercantilists also played an important role with their theories. They considered the accumulation of money to be important and money as a determining factor of economic growth. They thought the state should play an important role in economy.

Keynesian economics and the formation of econometrics had a great impact on the development of growth theories. The combined work of a mathematician and an economist resulted in a basic formula [5] for the production function:

$$Q=A \cdot L \cdot K \tag{1}$$

(Q= quantity of production, L= labour input, K= capital input). While the main aim of the production function is to use resources optimally, the essence of the Cobb-Douglas-function as a model of econometrics is to reveal the characteristics of recourse-utilization of a country, region, town, economic sector etc. in a certain period.

In connection to this was the creation of the calculation of marginal productivity, marginality of labour and capital. The formula of the Euler- thesis [6] is:

$$\alpha Q/\alpha L \bullet L+\alpha Q/\alpha K \bullet K=Q \quad (2)$$

Robert M. Solow attempted to create an extension to the Cobb-Douglas-theorem, he added technological progress as a new factor. In his model he typified growth only by the progress of time, (t):

$$Y=f(K, L, t) \quad (3)$$

Polónyi analyzed the connections of education and economics in his book and he emphasized the role of knowledge and technological growth [7].

We can group the theories on choosing a site as follows:

- In the first third of the 19th century the school of Thünen on spacial settling of agriculture. The factors: production – minimizing (of) transport costs.
- Years of 1900-20 (Weber, Predöhl, Palander) theories of industrial sites. Factors: production – minimizing (of) the main production costs.
- Years of 1930-40's (Lösch, Hotelling) theory of monopolistic competition. Factors: consumption – maximizing of revenues.
- Years of 1950-70's (Isard, Greenhut, Smith) theories of regional production functions. Factors: production, consumption, infrastructure, optimizing of mathematical models.
- From the 1970's on: Stöhr, Maleczki Scott: complex, interdependent locating-decisions. Factors: innovation, qualified labour, high-tech industries [9].

The fifth stage among the site-theories (Stöhr, Malecki, Scott) from the 1970's emphasizes the importance of innovations based on microelectronics and informatics due to the improvement of infrastructure. That's why factors, which are hard to define in numbers, have a more and more important role in site-decisions, e.g., creative and highly qualified labour, the state of the environment, and the service of settlements. As a conclusion we can say that nowadays complex, interdependent site-decisions are made [9].

Similar to the formation of site-choosing models there is also a tendency for creating an optimal city model. The definition of an optimal town/city could be different in different ages. Today a number of complex, sometimes independent, but mostly interacting factors together can make an optimal city.

3. Methods to compare or typify cities

Several researches dealt with the competitiveness and comparison of cities. Let's see a few examples.

A study in 2008 analyzed 60 cities [10]. The author was the first to make an analysis based on a so-called Global City Index. The aim of this study was to get an answer to the following question: how shall a city become global? His answer and conclusion:

there is no correct way for a city to become global. What do cities have to do in order to develop their international profile? They can follow for example any of the „tried-and-true models". In the study we can see different solutions of a couple of the 60 global cities from the year 2008 and how they improved from urbanization and globalization.

The biggest cities in the world help the evolution of global agencies and serve as centres of global integration. These cities are the engine of their country's growth and the gates to the region's resources. The history of globalization and the history of urbanization can be seen from different aspects. The Global City Index ranks metropolises based on 5 dimensions: business activity, human resources, exchange of information, cultural experience, and political commitment.

The study is looking for an answer to whether or not there is a winner taking every value into consideration. The result shows that there is nothing like "the perfect global city". Not one of the cities dominated in every dimension of the index, but there are close values in some particular fields [11].

The pressure to expand market generates an increase in contradictions of interests. Most of the western European cities began to prepare for the competition, for the sake of its citizens and companies, two decades ago. In their development strategies they kept in mind that:

- among the determinants of the economic growth the quality of housing, the cultural, scientific, technological surroundings of the settlement, and the favourable housing conditions came first;
- the intensity of connections among European cities is increasing, and the role of availability and accessibility of cities is increasing;
- cities offering a complex supply of services and facilities, having an adequate management will be appreciated in international markets;
- the influence of international governments is decreasing, the importance of regional governments, and European supranational institutions is increasing.

These are the important bases of the quality and liveability of a city. In addition, the availability of welfare and the complex services in every field are also of great importance.

In chart 8 we can see the factors determining the state of „competition" in the international example of Horváth. The location of industrial centres, the production structure and experimental and educational basis take the first 4 places from the 11 factors listed below (that means economy and education + research come in first place). Factors contributing to the liveability are also emphasized.

Table 1. Factors influencing the position in the city hierarchy (source: Horváth 2007, 11)

1.	Presence of an operating centre of big industrial groups
2.	Diversification of the production structure
3.	Research centres of higher education
4.	Development centres for experiments
5.	Infrastructure ensuring the quick movement of population and information (air traffic, motorway, telecommunication networks)
6.	The level of relation-systems ensuring the flow of information and ideas (conferences, programmes, exhibitions)
7.	Service networks of production (business consultancy, marketing, advertising)
8.	Financial resources, supporting systems
9.	Innovation-oriented development strategy, city arrangement plans
10.	Easy of access of educational, cultural, relaxing and sport establishments
11.	Districts meeting a high-level living standards

There are significant differences among the conditions of application of new drives in growth in big cities. Horváth highlights 8 cities in his analysis as an example. The major part of the differences in the figures can be explained by the specialities of the national politics, and in some cases the effects of the regional structural problems can also be observed. The study was done using twenty indexes of production, finance, research and education, air-transport, fair- and exhibition-organization, politics and diplomacy, completed with environmental features. A similar analysis was done by *Piero Bonavero* in 1997 on the international functions of the Italian town-network. To define the indicators is very important but in many cases it is hard to compare them in a complex system because of the lack of data. Infrastructural facilities and the approachability are indispensable for a city to be successful. Without these factors a city can hardly be attractive as a capital to foreign enterprises. Outstanding universities, expertise, a great number of museums or a low CO_2 emission are all in vain if settlements are not easy to approach, and they cannot be really attractive. I do believe that approachability is an important basic factor for investors, when they make their decisions.

How important is it to invest in knowledge and human capital? Zoltán J. Ács is dealing with this question in his work [12]. Based on studies of several other researchers he reveals the importance of human capital and knowledge in a regions' life in the long run. "The coordinated and efficient cooperation of government, local governments, schools, economic organizations, mediator-organizations and scientific research is indispensable for the success of innovation activities" [13]. All these factors contribute to the competitiveness of big cities and the emphasis lays on their coordinated operation in addition to the size of its population, facilities and former events in history.

The competitiveness of regions and towns is not only for itself. The main aim of the simplification is to improve the welfare and living standard of the population. Lengyel elaborated in the Pyramid model to measure the competitiveness of regions. Its logical structure has three levels based on each other containing the measurement of the competitiveness of a region and the factors influencing competitiveness [14]:

- Basic categories are indicators, which make the measurement of competitiveness possible (income, productivity of labour and employment).
- In the category of basic factors are economic factors, which directly determine the basic categories of competitiveness, if these factors are developed the competitiveness of the region can improve and the economic growth can speed up.
- On the lower level of the pyramid there are the success factors, they have an indirect influence on basic categories and on basic factors; these factors change only over a longer period [15].

4. Factors contributing to an optimal city

Forming and developing the urban network depends on city-planning and – management. (reasonable short-medium-long term utilization of resources) and on the contribution of the city to the country's development. It also depends on state support for cities (operating and developing costs, their utilization and proportion). In the judgement and "contest" of cities sustainable economy and liveability have an important role. The question arises: what kind of cities can be optimal i.e., are cities and their institutions that are operating sustainable good to live in? Connected to growth theories in economics the notion of economies of scale and Ricardo's theory of comparative advantages arise. According to both theorems the quantity of output is very important and so is the decrease of the average cost parallel to increasing quantity.

Lengyel defines the following factors as basic categories in his competitiveness pyramid model: GDP per inhabitant, scale of labour productivity, level of employment, openness of the economy, and its globalness.

Beside the basic categories, which show a certain order among settlements and regions, some general factors can also be listed serving competitiveness. They are systematized into the group of basic categories and success factors. These factors contribute to the fact that working capital flows into the settlement. If a city is easy to approach, has a regional attraction, has experts with adequate knowledge, small enterprises are well developed, and besides all of these the city is liveable, which means there are high standard of services at the population's disposal then it is attractive. Competitiveness means the successfulness of the city.

A group of specialists from the World Bank defines competitiveness as the aim of urban development. According to their perspective competitiveness of a city is the ability of a city to produce and sell products (goods and services) at a fair price (not exclusively at a low price), compared to goods of other urban regions [11]. Indicators used for analyzing competitiveness are sorted into four groups [16]:

- Economic structure: composition of branches with an influence, improvement of productivity, quality of investments, size of investments, speed of structural-change, characteristics of enterprise strategies, local competition, sensitivity of local suppliers and customers etc.
- Regional composition: age structure of population, distribution of income, level of infrastructure (transport, telecommunication, energy, industrial parks), natural resources, state of the environment, financial services, real estate market, local taxes, image, etc.
- Human resources: size of labour market, amount of working hours, unemployment, education, R&D institutions, wages, income tax, role of trade unions etc.
- Institutional environment: economic policy of central government, central taxes, laws against monopolies, local government programmes, efficiency of local politicians and local institutions, local commercial networks, entrepreneurial skills, corruption etc.

Is it necessary to check other factors if we wish to analyze the competitiveness of cities if we want to know how an optimal city can be? Does an optimal city exist? What kinds of factors determine it? What kind of effects do the changes of factors have on cities? What can be the key-factors in cities' future, which do not turn over the optimal (as far as it exists) city-structure?

5. Description of suitable mathematical methods

The aim of the model is to give us an answer to what kind of factors and size of population in different cities are needed in order to reach the optimum, or how the change in key-factors influence the city. We tried to be simple while creating the model. As factors influencing the choice of site changed so did site-models as well. It is possible that factors influencing the optimal city changed in different time periods as well. Today complexity is characteristic for site-theories containing environment, liveability, services and creative work. This could also be characteristic for cities, so the attempt to „optimize cities in a complex way" is not an easy job.

Based on economic development theories we can define following key factor groups:

- Capital (enterprise(s)): K
- Population: L
- Income: Y

These are known as the basis coefficients of the productivity function. Other indispensable factors are connected to it, such as:

- Infrastructure: I
- Education/ training: S
- Free-time: F

A fuzzy neural net can be the theoretical solution in order to create the model. After determining the different basic input factors output phenomena arise during the operation.

The fuzzy neural networks (FNN) are hybrid intelligent systems of soft computing technique, and they are very efficient in dealing with nonlinearly complicated systems, where linguistic information and data information are used parallel [18].

A fuzzified neural network means such a FNN where inputs, outputs and connection weights are all fuzzy set (fuzzy numbers). The α—cut learning and the genetic algorithm (GA) for fuzzy weights, are the two most frequently used methods for design learning algorithms for regular FNN's. A nonlinear fuzzy model with *n* inputs and a single output can be set by constructing a three-layer fuzzified neural network [17]. The input–output relations:

Input units:

$$o_{pi} = x_{pi} \qquad \text{i=1,2,...,n} \tag{4}$$

Hidden units:

$$O_{pj} = f\left(Net_{pj}\right) \qquad \text{j=1,2,.....,nH} \tag{5}$$

$$Net_{pj} = \sum_{i=1}^{n} o_{pi} \cdot W_{ji} + \Theta_j \qquad \text{j=1,2,....nH} \tag{6}$$

Output units:

$$O_p = f\left(Net_p\right) \tag{7}$$

$$Net_p = \sum_{j=1}^{n_H} o_{pj} \cdot W_j + \Theta \tag{8}$$

where

W_{ij} – fuzzy weight from the *i*th input unit to the *j*th hidden unit

W_j – fuzzy weight from the *j*th hidden unit to the output unit

Θ_j – bias to the *j*th hidden unit

Θ - bias to the output unit

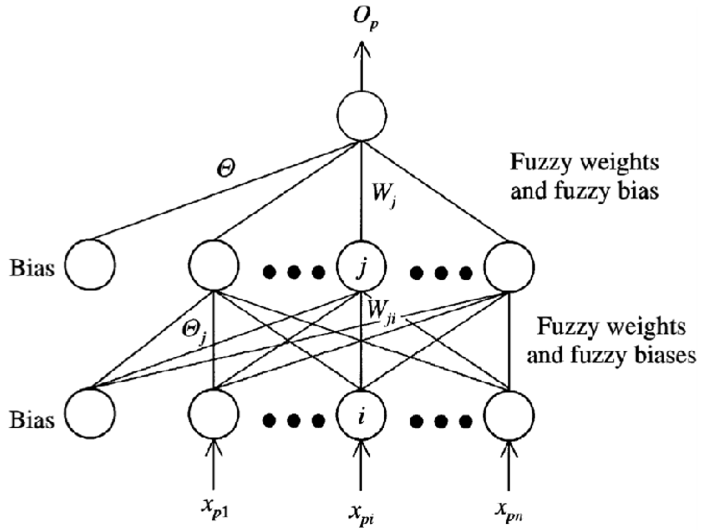

Figure 1 Architecture of fuzzified neural network [17]

This fuzzified neural network is shown in Fig. 1. The activation function in the hidden and output units can be:

$$f(x) = 1/ \{1 + \exp(-x)\} \tag{9}$$

The calculation of the input–output relation of units is based on fuzzy arithmetic, that can be used for computing the h-level set of the fuzzy output O_p from the fuzzified neural network. Thus the given neural network can be an interpretation of a nonlinear fuzzy model that maps the non-fuzzy input vector $x_p = (x_{p1}, \ldots, x_{pn})$ to the fuzzy output O_p.

Let the input parameters of a given city are

$x_{p1} = f($ *Capital, K*$)$

$x_{p2} = f($ *Population: L*$)$

$x_{p3} = f($ *Income: Y*$)$

$x_{p4} = f($ *Infrastructure: I*$)$

$x_{p5} = f($ *Education/ training: S*$)$

$x_{p6} = f($ *Free-time: F*$)$

and

O_p is the actual rank of that given city on a competitive list like [19].

The fuzzy neural net is considered to be trained, if the set of input parameters can produce the real rank with an acceptable error. By training the neural net the relative importance of the presumed acting factors can be determined, thus pro-active development policies can be established and verified.

6. Conclusion

There is a growing need for global strategies, and a harmonization of all institutes and people concerned in the urban development process. These have to go over the borders of individual cities and settlements. Each level of the government – local, regional, national and European – has its own responsibility for creating our cities' future. In order to have a real efficient multi-level government, it is necessary to improve the coordination among regional policy, and create a new sense of responsibility for the integrated urban development. It also has to be ensured that people realizing this policy on every level get the general and interdisciplinary knowledge and ability to form towns and cities as sustainable communities.

Keeping the sustainable economic growth in mind we wished to give a short essay about cities and their competitors with the help of profound analysis of economic planning methods, and we attempted to create a model of optimal towns and cities. These beginning steps might serve to be useful when creating the model of an optimal town, which is able to develop and is nice to live in.

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Predicting Cushion Characteristic on New Type of Environmental Friendly Foam

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Abstract In this paper packaging device is in investigated which can be a critical component in the defence against the logistic stresses. This device is the foam based move damping or cushioning system. The continuous developing of the materials give us the possibility to apply new and possible environmental friendly packaging (EFP) materials. To apply these materials we have to know many parameters for example the cushion characteristic. We investigate the possibility of a predicting method to make the development process easier.

Keywords: cushion curves, EFP, packaging development

1. Introduction

If we investigate a product – packaging system, we confront with many important question. In this article, we write about that segment which could be a critical element in the application of cushion materials. This problem is the constructing and designing the cushioning system. Predicting and choose the suitable material quality and thickness for the product, is works well in the field of common synthetic polymers, but we don't know how it works with EFP cushions.

However the synthetic polymers fulfill the cushioning function, the environmental aspects stronger and stronger in the designing of product – packaging systems. So analyzing the Life – cycle of these materials, we will get a not so positive picture. The balance of benefits and disadvantages are continuously changing and the problematic questions of the packaging waste problem grow the group of negative parameters. To solve the littering problems, the possible application of environmental friendly foams going to be more-more important. To substitute these common plastics, we have to know many parameters [1].

In the first half of the article we define those basic information in the field of biodegradable materials which we have to know. These terminus – techniques' are quite new definitions in the field of industrial packaging. We also define those parameters which we have to know about the cushion dynamics.

In the second part we try to implement a predicting methodology for an environmental friendly and biodegradable cushion material. This progressive analysis based methodology is well works in the synthetic foams.

2. "Environmental friendly" cushions in the packaging

If we investigating any statistical figure in the field of packaging like the figure below, we easily declare that the plastics means a huge part from the packaging generated wastes. From that percentage, the foams means cc 10% as weight, but it is easily countable that it is a huge volume. So these industrial applied plastic foams highly grow the packaging waste volume.

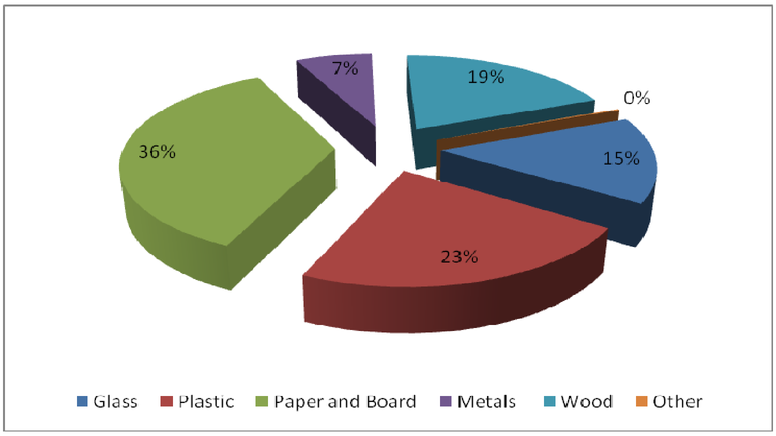


Figure. 1. Quantities of packaging waste generated in Hungary (100%: 968.067 ton in 2007) (source: epp.eurostat.ec.europa.eu)

In the initial situation, when a new product – packaging system developed, many times, the engineers gloze over about investigating the possible applied packaging material's life cycle. The cost only counted about the direct costs and they overlooking about the waste costs and other important costs. The false developed system will show disadvantageous quantitative and qualitative facts and parameters.

Well known example for this kind of development, when the logistic environment had defined regardless which caused product damage. The average answer for this problem is the overpacking (for example with extra or higher density foams), which cause extra costs and additionally won't solute the product damage problems.

On a rough estimate ten years ago, the common synthetics plastics, based on petrochemicals, had got more and more focus, because as the prices, as the regulations became higher and more severe. To solve these problems the material science, going to get a solution for the packaging engineers. The new environmental friendly materials possible be able to pass those requirements which defined by environmental and packaging standards. The group of the applicable materials which can substitute synthetic foams are continuously changing, as the investigation, test and development of these materials and publicized by other writers.

The following table is well illustrating those materials, which are going to get higher focus in the field of industrial packaging development [2].

Biodegradability			
Fully biodegradable	- PBS - PBSL - PCL - PTMAT - etc…	- Strach blends (with bio-degradable fossil-based copolymers) - PLA blends (with biodegradable fossil-based copolymers)	- TPS - Strach blends (with bio-based and bio-degradable copolymers) - PLA - PHA - Cellulose acetat - Regenerated cellulose
Non- biodegradable	- PE - PP - PET - PVC - PUR - ABS - etc…	- Starch blends (with polyolefin) - PA 610 - PET from bio-based ethylene - PUR from bio-based polyol - etc…	- Bio-based PE - PA 11 - Bio-based PB
	Fully fossil-based	*Partially Bio-based*	*Fully bio-based*
	Biobased raw material		

Figure 2. Current and emerging bio-based plastics and their biodegradability

To understand the processes and tendencies of environmental friendly foams, we have to clearly define those terms, which are appears in the field of any kind of degradability. The following flowchart well illustrates the simplified process of degradation. There are many papers, which are well defined the details of these processes, so we don't write the details of the process [3] [7]. Additionally we only cite some important terms:

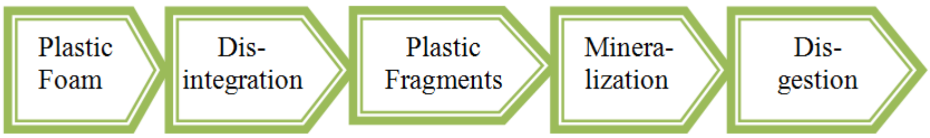


Figure 3. The schematic figure, of a degradation process (source: own drawing)

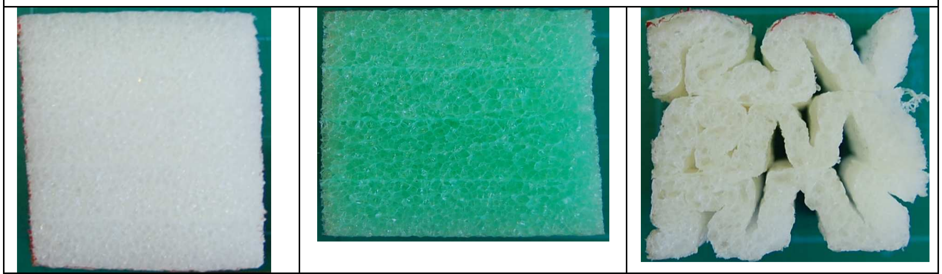
Biodegradable: Capable of undergoing decomposition into carbon dioxide, methane, water, inorganic compounds, or biomass in which the predominant mechanism is the enzymatic action of microorganisms, that can be measured by standardized tests, in a specified period of time, reflecting available disposal condition [4]. Potential of a material to be degraded which is caused by biological activity especially by enzymatic action leading to a significant change of the chemical structure of the material [5].

Compostable: Degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds and biomass at a rate consistent with other known compostable materials and leave no visually distinguishable or toxic residues [4] [6].

Degradation: An irreversible process leading to a significant change of the structure of a material, typically characterized by a loss of properties (e.g. integrity, molecular weight, structure or mechanical strength) and/or fragmentation. Degradation is affected by environmental conditions and proceeds over a period of time comprising one or more steps [4] [5] [6].

Disintegrating: The falling apart into very small fragments of packaging or packaging material, caused by a combination of degradation mechanisms [4] [5] [6].

On the following figures, the cross-section of 3 type of cushion material can be seen



Sample 1.	Sample 2.	Sample 3.

Figure 4. 3 type of foam, applied as a cushion material (source: own photo)

Normal PE foam with 35 kg/m^3 density, (from only one layer). The solutions if the material became waste are the followings: recycling after sorting or the energetic utilization

Multilayered PE foam (35 kg/m^3 density) with additive, which can accelerate the degradation process of the material.

Starch based, and multilayered waveform foam (33 kg/m^3 density). The construction is based on absolutely natural materials, so it becomes biomass as a packaging waste [8].

The second part of this paper, we introduce the basic background of the cushioning and investigate, the adoptability of a new type predicting methodology for a environmental friendly cushioning.

3. Methodology to predict dynamic characteristics

A mechanical shock or impact occurs, when an the packaged products's position, velocity or acceleration suddenly changes. A shock may be characterized by a rapid increase of acceleration (x) followed by a rapid decrease over a very short time (t).
During the logistic link it can appear as a dropping, throwing and other abuses caused by the manual loading, unloading and handling of packages.

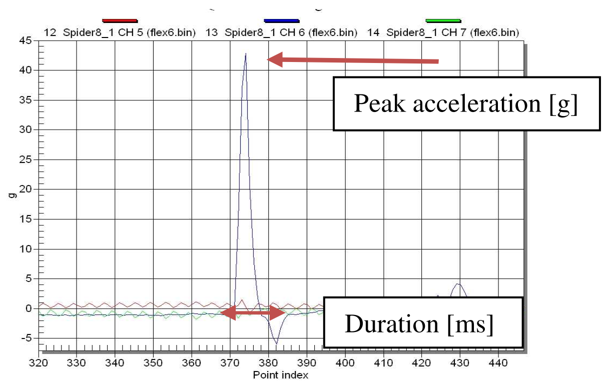


Figure 5. Registered shock during a drop on a packaged product (source: Authors)

In cushioned product packaging system, surely the cushion's aim to decrease and decelerate these critical values as it possible.

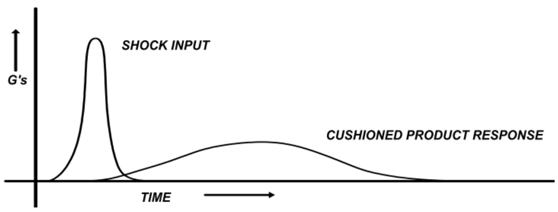


Figure. 6. Idealized shock input and cushioned response (source: Authors)

To make the right and suitable decision about the possible application cushion material, we know much mathematical coherence and we have some initial information about the material. One of the most important in these cases, the cushion curve of the materials.

Cushion curves are graphical representations of a foam material's ability to limit transmission of shock (called *G* level) to a product. *G* level is plotted along the vertical axis versus static loading (weight divided by bearing area) along the horizontal axis. Curves are specific to a particular material, a particular density, and a particular drop height. Simply consulting the cushion curve will visually tell how many *G*'s will be transmitted for a given drop height, cushion thickness and static loading [9].

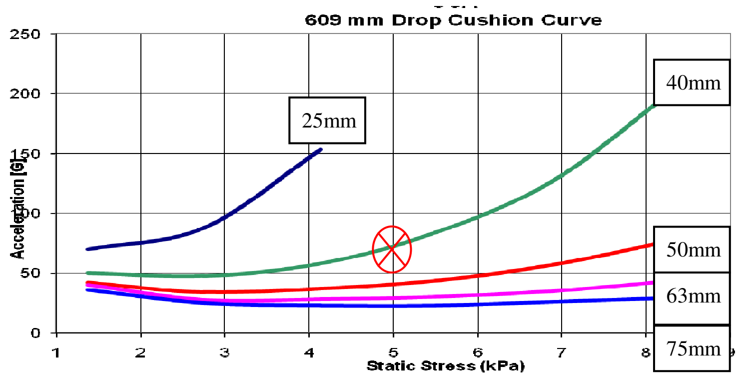


Figure 7. The cushion characteristic of an environmental friendly cushion (cc40 mm thick material at 5 kPa static stress, with 73 g)

This method for constructing cushion curves is based on standardized procedure. It is possible to overcome the limitation of selected data, but the process for collecting this information is very time consuming and resource intensive. To generate a full set of cushion curves (range of drop heights, about seven cushion thicknesses) would require somewhere on the order of 10,500 sample drops and over 175 hours of test time. Even more samples and time would be required to fill in the data for other cushion thicknesses and drop heights [9], [10].

4. A new method to calculate the cushion curve on new packaging materials

There can be a possible way if we want to simplify the process of generating cushion curves, and to give the ability to generate an unlimited number of curves with any set of variables (i.e. any drop height, any thickness, any static loading). This method is based on dynamic stress versus dynamic energy. This method is to realize material properties of a cushion can be described by a relationship between the specific variables of static loading, drop height, cushion thickness and *G* level. These are very familiar conditions which are used in traditional cushion curves. Instead of testing all variables to draw cushion curves we can reduce all combinations of drop height, static loading and thickness into a single equation that is able to generate any cushion curve we would like for given specific material.

The dynamic stress can be defined in *G*·s (*G* times static loading), and the dynamic energy can be defined as s·h/t (static loading times drop height divided by cushion thickness).Both of them have units of Pascal (*kPa*).

This method says that for any calculated energy, *G* can be predicted. If we want to compare predicted *G* levels (from *G*·s) to actual *G* levels from the published cushion curve in different combinations of (s), (h) and (t), (*G*) levels can be predicted very accurately.

First step,

You have to set the maximum and minimum limits on the energy absorbed. Because of energy = *sh/t*, the minimum energy corresponds to the smallest *s*, the smallest *h*, and the largest *t* that you want data for. The maximum energy corresponds to the largest *s*, the largest *h*, and the smallest *t* that you want data for.

Second step,

Divide the energy range in step first into about 5-10 approximately evenly spaced points. If the range 5 to 100 kPa is used, then test for energies in steps of about 20 kPa. You could for example choose 9 different energies equal to 20, 40, 60 . . . . . and 100 kPa.

Third step,

For each of the energies chosen in second step, select five-six different combinations of (*s*), (*h*) and (*t*) values that give this energy. In this example these are 6 combinations listed in the range in second step. For example, six different combinations of (*s*), (*h*) and (*t*) that give *sh/t* = 20 are:

Table 1. Variables for calculating dynamic energy (source: own measurement)

Static loading	***Heigth***	***Thickness***	***Dynamic energy***
s (kPa)	h (mm)	t (mm)	(kPa)
1	400	20	20
2	300	30	20
3	200	30	20
4	200	40	20
5	120	30	20
6	33	10	20

Next, we have to perform these 6 drops on the cushion tester (or drop tester). For the first drop, we can set the cushion tester up for an equivalent free fall drop height of 400 millimetres, and we can select a cushion sample with an actual thickness of 10 mm. We have to add enough weight to the platen to achieve a static stress of 1 *kPa*, and drop the platen. The shock pulse can be captured the peak acceleration (*G*) by recording machine (in this way we use HBM - Spider 8). These have to be completed for the six drops corresponding to an energy of 20 kPa. Now we can summarize the experimental data in a table like table 2. The *G* values in the 4th column come from the drop tests. Sample numbers are used for illustration purposes. The last column of this table shows the calculated stress values corresponding to an energy of 20 kPa.

Table 2. The calculated and performed G's level in dynamic energy of 20 kPa (source: own measurement)

Static loading	Height	Thickness	Captured G's	Dynamic energy	Stress = G·s	Average (kPa)
s (kPa)	h (mm)	t (mm)	G (g)	s·h/t (kPa)	(kPa)	
1	400	20	68,5	20	64,5	70,1
2	300	30	37,5	20	75	
3	200	30	26,8	20	80,4	
4	200	40	17,9	20	71,6	
5	120	30	13,5	20	67,5	
6	33	10	9,8	20	58,8	

The mean in this case is 70,1 kPa and the standard deviation is 3.67 kPa, which is 5.2% of the mean.

Fourth Step,

Repeat step third for each of the energies (doing on the six levels of the total range of 20 – 100 kPa) in the range chosen in second step and construct the stress vs energy relationship shown below. The stress values listed are the means for the 5 replicates tested for each energy. The variations are the standard deviations expressed as a percent of the mean. Sample numbers are used for illustration purposes.

Table 3. The calculated acceleration (G) on each static loading for a given material (source: own measurement)

Dynamic energy (kPa)	G's (g)	Variation in percent (%)
20	70,1	5,65%
40	106,18	1,81%
60	127,58	4,28%
80	316,45	7,11%
100	785,56	6,07%

Fifth step (optional),

Fit an equation to the stress (G) vs energy data. The relationship between stress and energy can usually be described to a high degree of correlation by the exponential relationship:

stress = $a\ e^{b(\text{energy})}$

where (a,b) = constants specific to foam type and density and (e = 2,71 constant)

This regression can be used to best fit this equation to the data. The next step is to plot dynamic stress versus dynamic energy, and apply a simple exponential curve fit to the data points (Power Trend-line in Excel), as shown in Figure 8.

Using the Stress-Energy Equation to Generate Cushion Curves

A simple spreadsheet can be set up to use stress equation to draw any cushion curve for a given material. An example is shown in Figure 8. Now we can simply change the drop height and/or thickness and plot *G* versus static loading (s).

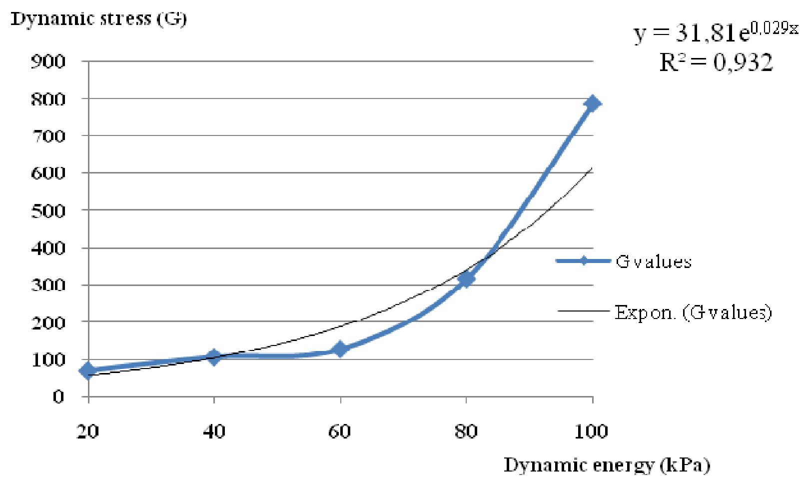


Figure 8. Dynamic stress versus dynamic energy (source: Authors)

The equation is now the Dynamic Stress-Energy equation that fully describes the cushioning ability of a given material. Also, this graph displays R^2 value, which is an indication of how well the equation fits the data. The 93% percent is extremely good. The equation shows the value for (a) is 31.81 and the value for (b) is 0.029. Now we have one equation that can be used to generate for any cushion curve for this material.

Notice: The detailed parameters and the test results are archived by the authors.

5. Conclusion

Curve fit correlation was excellent across all number of drops, almost always over 90% and in many cases over 95%. Since the stress-energy method relies heavily on energy absorption (static loading, drop height, thickness), great care needs to be taken when measuring these variables. By this method we do not have to test each variables of a given material (i.e. any drop height, any thickness, any static loading). By means of this method we are able to define a cushion curve of a given materiel in approximately 2 hours. This method is very familiar which is used in traditional cushion curves, but instead of testing all variables to draw cushion curves we can reduce all combinations of drop height, static loading and thickness into a single equation that is able to generate any cushion curve we would like for given specific material.

The main consequence of the investigation was that, we are able to implement the method for a new environmental friendly packaging material, which helps us to apply these materials as soon as possible.

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