# Can the Increasing of Energy Consumption of Information Interchange Be a Factor That Reduces the Total Energy Consumption of a Logistic Warehouse System?

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**Abstract.** The studying of relationships between subsystems, creating a logistic warehouse system, is one of the most interesting issues in terms of designing and optimization of logistic warehouse systems. It is important to use of these relationships in practice. The authors propose to assume the energy consumption of the system (which was calculated according to the described model), as an index that allows to compare individual options. Thanks to this model it is possible to match the system of information interchange to the given equipment, and vice versa. Three warehouse options were analyzed from the given warehouse system point of view. Three options of a warehouse system of information interchange were tested from the given warehouse equipment point of view.

**Keywords:** optimization of logistics system, energy consumption, bar codes.

## 1 Introduction

Nowadays, many requirements which were established for the logistics warehouse systems have changed. Energy consumption is very often one of the most important elements in the processes of the planning, the estimation of efficiency or the revitalization. Energy is defined as a balance of energy that was delivered to the logistics system. This energy can be for example connected with the rotation of unit loads. It is worth to emphasize, that there is no universal index, thanks to which it would be possible to evaluate logistic warehouse systems, taking the energy consumption into consideration. In the literature there are some attempts of creating this kind of index, for example: Directive of the European Parliament and of the Council 2006/32/WE of April 5, 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC; renewed Lisbon Strategy and National Cohesion Strategy (2007-2013).

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"United Nations Framework Convention", colloquially called The Kyoto Protocol (December, 1997 and it has been in force since 16 February, 2005). As a result of agreements, a decision was made according to which the "Index EEI" was established as a system of energy efficiency classification. This index describes the efficiency of devices. Within the index there is a scale (from A to G), where "A" is the best class and it means that the efficiency of the device is the highest and "G" is the poorest class, and it means that the efficiency of the device is the lowest. There are also some subclasses, for example A+ or A++. These classes are calculated from the proportion of a year-long energy consumption of a given device to the standard energy consumption of the device, which is defined by specific regulations.

The information connected with this subject matter was collected on the basis of reviews of the research database: EBSCO, COMPENDEX, PROQUEST, Baztech, e-Journals: [1-13].

89% of transport energy in Poland is consumed in the road transport and 5.6% of energy is consumed in the rail transport. The rest of energy is consumed in the air transport and minute quantities in inland navigation and cabotage.

A method of calculating the energy consumption of logistic warehouse systems will be presented in this paper. This method can be used to verify the system of information interchange in logistic systems. Because they have no tools, in some cases designers are acting according to their intuition and experience in these types of decisions. Apart from these, there are no analytical tools, which can help in the selection of warehouse system elements [5, 2].

In the second subsection of this paper a method of calculating the energy consumption will be described. Then, example calculations will be presented and results will be described. Conclusions will end the paper. The author provides a wide range of literature.

## 2 Digitisation and Calculation of Energy in the Model

The level of the terminal floor, in front of the entrance to the warehouse (where the reloading takes place) was assumed to be the reference level – the energy of a pallet that is received to the warehouse amounts to 0 (in warehouses without temperature regimes – this problem is going to be touched on), so every movement of the pallet with the material generates energy changes. There is an assumption, that the energy is equal to the work that has to be done to move the pallet [3].

$$E_E = E_P + E_S + E_Z + E_C + E_W \tag{1}$$

Where: $E_P$ - energy, which is necessary to lift the pallet; $E_S$ - energy, which is necessary to lift empty forks; $E_Z$ - energy which is necessary to transport the pallet; $E_C$ - energy which is necessary for a truck travel without a load; $E_P$ - energy which is necessary to execute tasks connected with the use of forks.

The potential energy can be calculated from the well-known formula E=mgh, but the kinetic energy has to be calculated on the basis of driving characteristic of conveyors and vehicles.

There is no formula in the literature, thanks to which it would be possible to calculate the energy of a forklift truck. So for the purposes of this research, the formula was created on the basis of the simplest case.

$$F = m \cdot a + m \cdot g \cdot \mu \tag{2}$$

where $\mu = f(mat1, mat2)$. The equation of the movement of the truck can be presented by means of relationship (3):

$$F(V) = m \cdot a + W_t \tag{3}$$

where: $m \cdot a$ - inertial force; $W_t = f_t \cdot Q$ - resistances to motion; $f_t$ - rolling resistance coefficient; $F(V)$ - driving forces.

Resistances to motion can be divided into basic and additional. The rolling resistance, suspension dumping, toe-in resistance and aerodynamic drag are included in the first group. The grade resistance, and resistances connected with the drawbar pull, the start-up and with the turn are included in the second group. The equation of movement has a form:

$$\xi \cdot m \cdot \frac{dV}{dt} + W_{r.coal} = F_N(V) \tag{4}$$

where: $\xi$ - ratio of rotor. Possibilities of energy recovery, short time of storing this energy and the conversion of this energy into different forms – all these factors are taken into consideration in this method.

The organization of the warehouse transport system: organization of the warehouse, of the work, of devices.

An assumption was made that there are: 1,2,…, m devices; docks (receiving docks and shipping docks) 1,2,3,…, s; storage areas (rows of racks/intermediate storage area) 1,2,3,…, k. The process of warehousing consists of receiving, storing, picking and giving the loads out. This model assumes that pallet unit loads will be used in the picking process there. In the process of unit load moving the following stages may be distinguished, starting with setting the unit load next to the receiving dock, through the process of storing and giving it out: receipt of a pallet (i); transport of the pallet (j); putting the pallet back on the chosen place in the intermediate storage area (l).

In some cases during the process, there are changes of devices between the stages i,j,l. Each stage is executed by a device, so the storing of pallet (a movement of the unit load in the transport-warehouse system) can be presented as three numbers (i,j,l), that present the number of the device, which is carrying out the warehousing.

The process of storing can be divided into single operations: $o_1$ - travelling of the empty forklift truck to the place, where the unit load is placed, $o_2$ - executing the task which is connected with the use of forks, $o_3$ - delivering the pallet to the $PP_1$, $o_4$ - return of the empty forklift truck to point M (readiness point), $o_5$ - reloading, $o_6$ - transport from the $PP_1$ to the $PP_2$, $o_7$ - reloading, $o_8$ - taking the pallet to the rack, $o_9$ - executing the task which is connected with the use of forks, $o_{10}$ - return of the empty forklift truck to point M (readiness point).

The data characterising each device is also given here: a single energy demand in the horizontal direction; a single energy demand in the vertical direction; the data is written as matrix ZE. The ZE is an m x 2 matrix.

$$ZE = \begin{array}{c} 1 \\ 2 \\ . \\ . \\ m \end{array} \begin{bmatrix} ze_{11} & ze_{12} \\ ze_{21} & ze_{22} \\ . & . \\ . & . \\ ze_{m1} & ze_{m2} \end{bmatrix} \tag{5}$$

Unloading, introduction of the unit load to the warehouse.

There is a set of n pallets, which are located in the particular dock. There is also information about these pallets:

The mass of the pallet.

The address of storing place within the warehouse.

The creation of the transport parameters matrix PT is the next step. This is an n x 5 matrix, where: $PT_{i1}$ = the mass of the pallet I; $PT_{i2}$ = the track of the unloading stage of the pallet I; $PT_{i3}$ = the track of the transport stage of the pallet i; $PT_{i4}$ = the track of the locating stage of pallet I; $PT_{i5}$ = the height of the storing of pallet I.

$$PT = \begin{array}{c} 1 \\ 2 \\ 3 \\ . \\ n \end{array} \begin{bmatrix} pt_{11} & pt_{12} & pt_{13} & pt_{14} & pt_{15} \\ pt_{21} & \dots & \cdots & . & pt_{25} \\ . & . & . & . & . \\ . & . & . & . & . \\ pt_{n1} & . & . & . & pt_{n5} \end{bmatrix} \tag{6}$$

It is necessary to define the technology of unloading for each pallet (unit load). Because there is a possibility of reloading from one device to the material handling device between some stages of the process, it is necessary to determine a single energy consumption for these operations. The matrix dimensions are m x m and there are three numbers (i,j,k), and each number executes a given stage of unloading. For example, the compositions of numbers (3,5,1) means that the first stage of the process is performed by device number 3, the second stage by device number 5 and the third stage by device number 1. The collection of these technologies for all pallets creates matrix T, where $t_{ij}$ – indicates the number of the device executing stage j of pallet I unloading process (i=1, 2, 3, ..., m; j=1, 2, 3)

$$T = \begin{matrix} t_{11} & t_{12} & t_{13} \\ t_{21} & t_{22} & t_{23} \\ t_{n1} & t_{n2} & t_{n3} \end{matrix} \tag{7}$$

Matrix Z is defined in the following way: $Z_{ij}$ = *>0* when the reloading from one device i to the second device j is possible and if it is equal to the single energy consumption of this operation there is no reloading

$$Z = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1M} \\ Z_{21} & Z_{22} & \cdots & Z_{2M} \\ \cdots & \cdots & \cdots & \cdots \\ Z_{M1} & \cdots & \cdots & Z_{MM} \end{bmatrix} \tag{8}$$

For each pallet and taking into consideration technology (T), it is easy to determine an elementary energy consumption. This energy consumption is going to be indicated as an n x 10 matrix O. Elements of this matrix are defined: $O_{i1} = ZE(T(i,1),1)$, $O_{i2} = ZE(T(i,1),2)$, $O_{i3} = 0_{i1}$, $O_{i4} = 0_{i1}$, $O_{i5} = ZE(T(i,1),T(i,2))$, $O_{i6} = ZE(T(i,2),1)$, $O_{i7} = Z(T(i,2),T(i,3))$, $O_{i8} = ZE(T(i,3),1)$, $O_{i9} = ZE(T(i,3),2)$, $O_{i10} = 0_{i8}$.

To obtain the energy consumption for each operation, it is necessary to correct elements of the matrix, taking the track, the load and the height into consideration. Coefficients of corrections are determined on the basis of the PT matrix. We obtain a *WK (n x 10)* matrix, which is defined as a matrix of the coefficients of correction of energy consumption for each operation and for each pallet.

After the operation of matrices WK and O multiplication, we will obtain matrix E, where the elements of this matrix correspond to the energy consumption for each operation and for each pallet.

The matrix multiplication is defined as:

$$WK_{n\times10} \otimes O_{n\times10} = E_{n\times10} \tag{9}$$

where:

$$e_{ij} = WK_{ij} \cdot O_{ij} \tag{10}$$

The total energy consumption is:

$$E_C = \sum_{i=1}^{n} \sum_{j=1}^{10} e_{ij} \tag{11}$$

The thermal energy is considered in the case of analysing warehouse systems with the temperature regime. In these cases it is important to take the heat exchange into consideration – the heat that penetrates walls, the ceiling and the floor of the warehouse chamber; the heat that was abstracted from cooled loads on the pallet; the heat which was given back by the air, which was unintentionally introduced to the chamber; the heat connected with the work of the radiator fan; the heat which is generated by people; and other kinds of heat, according to the equation.

Modern devices in warehouses are very often equipped with technical systems, which allow energy recovering, energy storing and converting it into different forms (by using heat accumulators, storage cells, pressure accumulators). What is more, there is also a possibility of analysing the utilization of solar energy (water heating, generation of electricity). The model was not tested in regard to taking a geothermal source of energy into consideration.

The flow of information in logistics system is described by the quantity and the cost of equipment which is needed to guarantee the flow of information. The energy which is necessary to the information interchange on the accurate level to guarantee the required warehouse turnover was also taken into consideration. . The energy of the system of the information interchange in the logistics warehouse system can be divided into: the energy of identification of elements and the energy of information transfer (in some cases the data transfer). In the paper, this problem was taken into consideration. Functionality of RFID marks which relies on the affiliation both to the first and to the second group was taken into consideration. These marks can be used to recording of actual positions of elements of the logistics system, in the context of minimization simple cycles of their work.

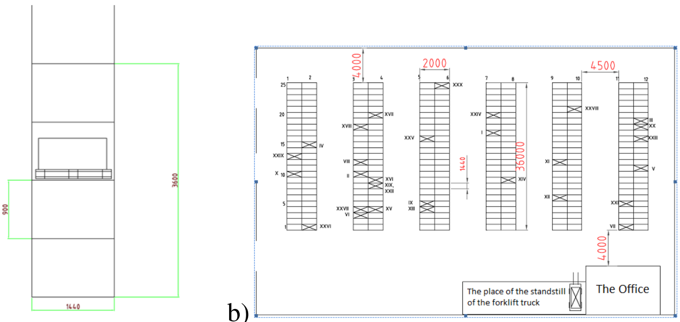
## 3 The Application of the Model to the Given Case

For the purpose of examination of the above cited concept, calculations were made for a given warehouse. The system of information interchange was matched with a given layout of racks and aisles. There were three options of information interchange: a) the printed information, 2) a mobile terminal with a docking station, c) a radio terminal. Values of several parameters, which describe the logistics warehouse system, were assumed for the purpose of making calculations easier:

*PR* – annual turnover of the warehouse (the number of unit loads – euro pallets – that move through the warehouse during a year) = 400000; *PD* – daily turnover of the warehouse (the number of unit loads – euro pallets – that move through the warehouse during a day) = 1231 (325 working days for a year); *Ph* – average number of unit loads that are serviced during one hour = 77; reloading of 1096 pallets per day, so there are 1500 rack slots and the weight of a pallet is 800 kg. All forklift trucks working in this warehouse are equal. Forklift trucks and all characteristics that are connected with them, are based on the characteristic of a JUNGHEINRICH EFG 316 forklift truck. There are 5 forklift trucks in the warehouse, but to make calculations clearer, there is an assumption that all tasks are executed sequentially (only one truck is working at the given moment). Forklift trucks move along straight sections and the truck speed amounts to 13 km/h. Rack slots are denoted (it is the number of the lane, the number of the place in that aisle and the number of the level, where the pallet with the load is placed). In the case of the warehouse, two docking terminals are placed on the sides of the building, and in the middle of the lanes. To make the calculations clearer, the authors make an assumption that the weight of each unit load in this warehouse is 800 kg.

The test consists in the simulation of transportation of 30 pallets (with the assumption that unit loads shipments are being delivered at the terminal). The mechanical energy which is necessary to execute all tasks is described by means of previous model. The coefficient of resistance to motion amounts to 0.1. Intermediate storage areas were generated with the use of Random Number Generator from the Windows Microsoft Office Package, where: (number of activity, number of door, number of lane, number of place, number of level): (1,3,7,17,5), (2,2,3,10,5), (3,1,12,18,3), (4,1,2,15,5), (5,3,2,11,2), (6,1,3,3,5), (7,3,11,1,1), (8,3,3,12,2), (9,2,5,5,1), (10,2,1,10,3), (11,1,9,12,4), (12,1,9,6,3), (13,1,5,4,4), (14,2,8,9,4), (15,3,4,4,1), (16,1,4,9,1), (17,2,4,20,1), (18,1,3,18,4), (19,3,4,8,2), (20,2,12,18,5), (21,3,11,5,4), (22,3,4,8,3), (23,2,12,16,3), (24,1,7,20,4), (25,1,5,16,4), (26,3,2,1,4), (27,3,3,4,4), (28, 3,0,21,1), (29,1,1,13,4), (30,2,6,25,5). The data is the same for each of three variants of the warehouse. There are five levels of racks in the warehouse (Fig.1).

a)




b)

c)

| Rack slots | Number of racks | Number of levels | Number of lanes | Number of slots in one lane |
|---|---|---|---|---|
| 1500 | 6 | 5 | 12 | 25 |

**Fig. 1.** Test warehouse: a) pallet rack, b) functional scheme of warehouse, c) parameters of action

### 3.1 The Determination of Pallet Movement Tracks on the Horizontal Surface

Unit loads are moved by means of forklift trucks. A forklift truck starts from the point called “standstill” and then it moves to the particular location to take a unit load. The forklift truck holds it and takes it away to the door. Then, depending on the variant: “1” it returns to the “standstill” point, “2” it returns to the docking station ( which are placed in the middle of lanes), “3” it starts a new activity.

The scheme of tracks is presented here for variant 1. To illustrate the transport process, the tracks for the firsts 5 orders are presented. These are results obtained from formula (12), for variants 1,2,3.

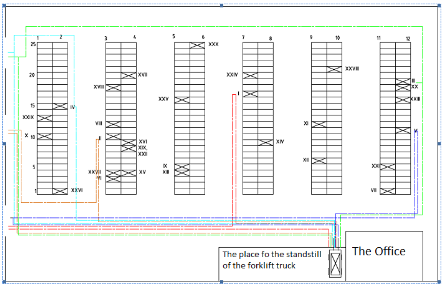



**Fig. 2.** The scheme of the tracks for the forklift truck in the warehouse number 1 (tracks 1-5)

$$\Delta s = K + 4{,}5 \cdot L_x + 2 \cdot NR \tag{12}$$

Where: *K – Constant length of the track covered by a forklift truck (drive from door nr 3, pulling out and return to the "standstill" point, then travel and return to the edge of the racks); Lx – Distance between racks (from the axis of the middle of an aisle, to the axis of the middle of the next aisle); NR – Distance between the edge of the rack to the storage place of a pallet – product of the slot width and the number of the slot* $NR = 1440 \cdot n$, *n – the slot number.*

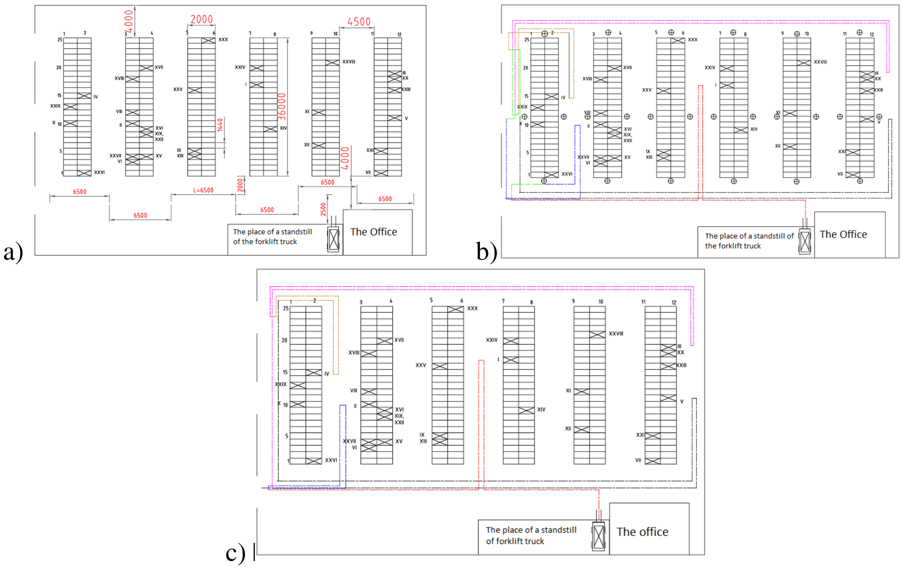



**Fig. 3.** Distances covered by a forklift truck in a) variant 1, b) variant 2, c) variant 3

### 3.2 The Work Connected with the Displacement of Pallets

The quantity of energy that is necessary to move 30 pallets by a forklift truck is connected with the characteristic of the handling equipment. In this example, three

Jungheinrich EFG 316 forklift trucks were used, and their driving characteristic is presented on the picture below.

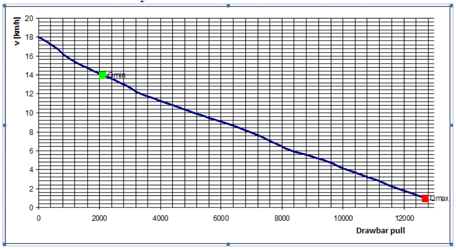



**Fig. 4.** Driving characteristic of a Jungheinrich EFG 316 forklift truck

Taking into consideration that $W = F \cdot \Delta s = E_K$ , the work executed by a forklift truck can be calculated from formula (3).

It results from the assumptions that the forklift truck moves with the speed of *V = 13 km/h*. During turning the speed decreases to 5 km/h. Authors make an assumption that the track that is necessary to turn, to brake and to speed up, amounts to 6m (straight line). The calculation of loss resulting from braking and accelerating gives the difference of given terminal speeds. The statement of calculation results gives the driving force.

The table shows that for the speed of v = 18 km/h, the driving force decreases below 0. It results from the fact that the forklift truck (for which calculations are made), can achieve a speed of v = 17 km/h. It is also important to remember about making turns at the speed of v = 5 km/h, manoeuvres connected with the pallet picking from the storage, travel to the axis of track and manoeuvres connected with the unloading next to the receiving dock. One manoeuvre is braking from the speed of v = 5 km/h to v = 0 km/h and then accelerating on a 2 meters long track. Statement of the tracks, which are covered by forklift trucks in the warehouse, are presented below.

**Table 1.** Statement of tracks for warehouses 1-3

| Warehouse nr 1 | | | | |
|---|---|---|---|---|
| Δs [m] | Number of turns | Track with turns 5 km/h [m] $\Delta_{sz1}$ | Track with straight segments [m] $\Delta_{sp1}$ | Maneuvers [m] $\Delta_{sm1}$ |
| 3637,1 | 171 | 1266,0 | 2371,1 | 240 |
| Warehouse nr 2 | | | | |
| Δs [m] | Number of turns | Track with turns 5 km/h [m] $\Delta_{sz2}$ | Track with straight segments [m] $\Delta_{sp2}$ | Maneuvers [m] $\Delta_{sm2}$ |
| 2599,51 | 119 | 954 | 1645,51 | 240 |
| Warehouse nr 3 | | | | |
| Δs [m] | Number of turns | Track with turns 5 km/h [m] $\Delta_{sz3}$ | Track with straight segments [m] $\Delta_{sp3}$ | Manuvers [m] $\Delta_{sm3}$ |
| 2339,76 | 116 | 936 | 1403,76 | 240 |

Results of kinetic energy calculations for individual warehouses are presented below.

**Table 2.** Results of kinetic energy calculations

| | Warehouse nr 1 | Warehouse nr 2 | Warehouse nr 3 |
|---|---|---|---|
| Ekp | 5712451,16 | 3964410,798 | 3381979,63 |
| Ekp5h | 4177209,76 | 3147755,224 | 3088363,616 |
| Ekp5r | 4177209,76 | 3147755,224 | 3088363,616 |
| Ek0h | 1080995,61 | 1080995,61 | 1080995,61 |
| Ek0r | 1080995,61 | 1080995,61 | 1080995,61 |
| Sum [J] | 16228861,92 | 12421912,48 | 11720698,09 |

### 3.3 Pallet Movement Tracks on the Vertical Surface

The potential energy exists in the transport process during the lifting and lowering of the transported pallet. According to the authors' assumption, the pallet lowering is realized due to the gravitation, and that is why it is also necessary to take into consideration a small amount of energy to prevent the forks striking into the floor. It has a small influence on the result of the calculations, so in this case this energy amounts to 20% of energy that is necessary to lift the forks (with or without the load). During the reloading of the pallet, the potential energy exists, when there is a movement of forks: first, when the truck receives the pallet from the rack slot, and second, when the pallet is delivered next to the receiving dock. The value of the energy in the first case is the function of the storage height, and in the second case it is constant because the pallet is placed on the one-meter platform next to the receiving dock. Each of cases occurs once during one reloading cycle. In the case of warehouse 1, 2 and 3, the first and the second type of reloading occurs only once (the weight of the transporter system amounts to 700 kg).

We multiply the lifting height (1 m) by 30 and it is the same for each warehouse. The value of the energy can be calculated from the formula $E_p = m \cdot g \cdot h$.

**Table 3.** Potential energy used in the process of moving 30 pallets [3], [4]

| Potential energy | | | |
|---|---|---|---|
| Warehouses | | | |
| $E_{p1'}$ | 414080,1 | $E_{p1}$ | 496896,12 |
| $E_{p2'}$ | 441450 | $E_{p2}$ | 529740 |
| $E_p$ [J] | | 1026636,12 | |

The total energy values necessary to move unit loads are presented below.

**Table 4.** Calculations of the total energy of each warehouse

| Total energy | | | |
|---|---|---|---|
| | Variant 1 | Variant 2 | Variant 3 |
| $E_k$+$E_p$ [J] | 17255498,04 | 13448548,6 | 12747334,21 |

## 4 The Analysis of the Calculation Results

Using the method from the second subsection, it was possible to calculate the energy consumption of moving the unit loads for three different variants. This model calculates the energy consumption taking into consideration not only the energy of forklift trucks, but also the energy consumption of the information interchange systems (matrix "O" – single energy consumption). The way of information interchange between the workers and the manager is the factor affecting the energy consumption. In variant 1, the forklift truck operator is given a printed order. He executes the task and then, after each completion he has to inform the manager about this task and then he has to get a new order. In variants 2 and 3 there is an automated information interchange. Each of these methods has a particular energy consumption that influences the energy consumption of the whole logistic system. Results are true for universal electric forklift trucks and typical operator terminals.

Also the making of the storage height higher will result in changing the energy consumption of the information interchange system, because it will be necessary to cover the additional space of the warehouse with radio-waves.

## 5 Conclusion

Several conclusions can be drawn from the calculations: the knowledge connected with the energy consumption of a warehouse system taking into consideration elementary energy consumptions (for example the system of information interchange) may be used when a decision is to be made about the choice of the information interchange system. Any simplest operations can decrease the energy consumption of logistic a warehouse system by 5%. The application of topical methodology of energy calculation allows performing a detailed analysis, not only in the context of the information interchange system.

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