# Intralogistics Systems – Optimization of Energy Efficiency

**Norbert Hafner**
Ass.-Prof., Deputy head
Institute of Logistics Engineering (ITL)
Faculty of Mechanical Engineering
and Economic Sciences
Graz University of Technology
Austria

**Florian Lottersberger**
Research Assistant
Institute of Logistics Engineering (ITL)
Faculty of Mechanical Engineering
and Economic Sciences
Graz University of Technology
Austria

*Material Flow Systems are core components of intralogistics systems. Optimization of their energy efficiency is an issue of growing importance. At the Institute of Logistics Engineering a 36 month research project was finished in 2014. We present the results of two main areas investigated. The first focal point is a generalized approach for energy efficiency and energy indictors. Indicators of conveyor and automated storage systems are detailed. The specific need and structure of representative operation cycles are illustrated. The second core research goal is on gathering valid optimization potentials of common types of conveyor systems. It is demonstrated that there are enormous potentials to increase efficiency based on electric drive units. Finally we present an outlook on a follow-up project for extended studies of the verified results over a further 36 month period.*

***Keywords:*** *Energy Efficiency, Material Flow System, Energy Indicator Model, Conveyor System, Storage System, Distribution Center*

## 1. INTRODUCTION

Automated Material Flow Systems (MFS) are main components of most in-plant logistic systems. As the MFS becomes larger their energy consumption also rises. In this context energy efficiency becomes a highly important issue in terms of both economy and environmental sustainability [1-8].

No standards for benchmarking and comparing energy consumption of MFS in relation to the complex systems and their operations are available.

Isolated standards for the efficiency of single elements only are specified (e.g. electric drives). Most of these only consider the nominal operational conditions, which are not valid for real operational situations.

A 36month research project - "Energy Efficiency in Material Flow Systems" (effMFS) was completed at the Institute of Logistics Engineering in 2014. This was funded by FFG Austrian Research Promotion Agency. In close cooperation with the industrial partner SSI Schäfer PEEM GmbH the research project focused on two main areas of interest. The first focal point was on gathering realistic optimization potentials for common conveyor system types. The electric drive technology used, the design of the drive train and the conveying construction as well as control and operation strategies to improve energy efficiency were all investigated [9-10]. The second core research area was a standardized and generalized approach for energy indictors (EI) of MFS. The general EI-model developed was additionally detailed for conveyor and automated storage systems. The goal that has been successfully reached is the ability to compare energy efficiency of MFS independent of manufacturers and technical solutions taking representative operation cycles into account.

Based on the effMFS project results a follow-up project was arranged, now bringing in three industrial partners (SSI Schäfer PEEM GmbH, SEW-EURO–DRIVE GmbH & Co KG and Anton Paar GmbH). The project "Energieeffizienz komplexer Materialfluss–systeme" (EEkMFS) started in April 2015. It is again funded by FFG for 36 further months.

In this paper we present the latest results of the effMFS project and we provide an outlook on the investigations in the EEkMFS follow-up project.

We will first focus on the target energy indicator (EI) system, showing the general approach, valid for all typical MFS devices. In this we will additionally illustrate the specific EI results for conveyor and automated storage systems.

A second focal point will be the optimized selection of drive systems for specific applications. Their energy efficiency and the improvement potentials must be known in order to make this selection. Related studies and specific measurement tasks were carried out and others will be processed in the follow-up project.

## 2. INTRALOGISTICS – ENERGY EFFICIENCY

In order to evaluate the overall energy efficiency (OEE) of a system, a structured general approach must be defined and worked out for the typical MFS. It is important to meet specifications for a general top-down MFS modularization. Total system boundaries and functional viewing areas or processes must be delimited (production, storage, picking ...).

Different system utilization, in terms of load and/or operation spectra, must be considered. For this purpose suitable specifications need to be set (representative workload levels).

Complex materials handling systems are built up of differing subsystems. A distribution center, as a repre–sentative use case, typically consists, between the incoming and delivery area, of a warehouse and picking system as well as consolidation and packing areas

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Correspondence to: Norbert Hafner
TU Graz, Institute of Logistics Engineering
Inffeldgasse 25e, 8010 Graz, Austria
E-mail: norbert.hafner@TUGraz.at
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(figure 1). These subsystems are linked to each other (e.g. by conveyors), so that the required material flow processes are realized.

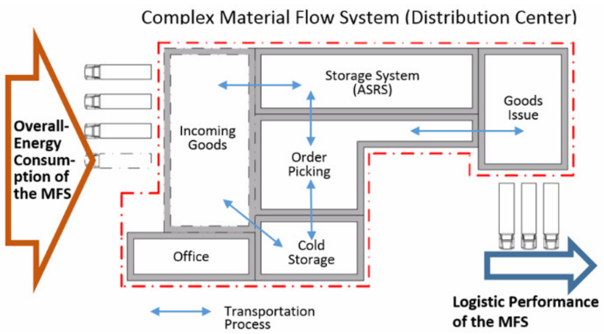



**Figure 1. Layout Distribution Center – use case for overall energy efficiency (OEE)**

### 2.1 Overall approach for energy improvements

Material Flow Systems (MFS) in intralogistics are typically designed to fulfill specific customer requirements. Thus no system is like any other and a simple or standardized comparison, in terms of energy consumption, is not possible.

Here structured and consistent basic methods have to be developed. The main aspects are standardized valid energy indicators (EI) and the methods for their calcu–lation. Also important is the ability to optimize the drive system design for MFS devices based on their specific dynamic behavior for representative operation cycles.

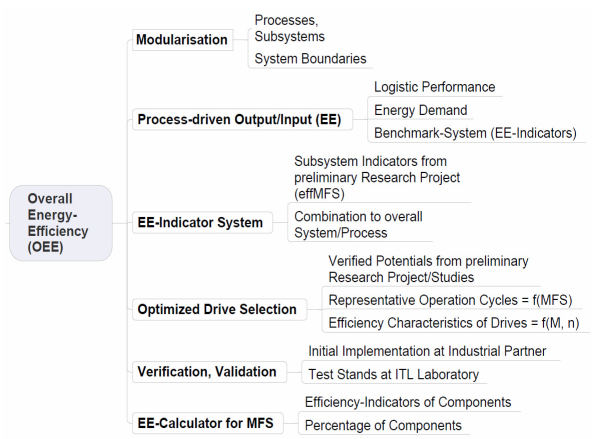



**Figure 2. Classification for energy efficiency improvements**

Figure 2 shows a classified structure of work-packages or targets for reaching the overall goal of comparable and improvable energy efficiency. These are discussed in detail in the following.

### 2.2 Modularization and classification

For the purpose of determining the total energy consumption adequately, the energy consumption values for the individual devices are required. In order to achieve comparability a standardized modularization and classification is needed.

The modularization of the total system, into functional units, achieves defined boundaries and interfaces, as well as a systematic meaningful structure (e.g. functional units to convey and store).

For the specified units a common classification is necessary. This must be done by representative parameters, e.g. pay load or storage capacity. An obvious way forward here is to focus on the class of fully automated systems and in the case of storage systems on the goods to person class.

In the next sections we concentrate on conveyor and storage systems. In the outlook we will sketch the planned extensions for the next few years.

### 2.3 Energy efficiency – benchmark of MFS

In addition to a standardized system structure (modularization) and unit specification (classification) a comprehensive energy indicator approach is needed.

The improvement of energy efficiency becomes possible when efficiency factors are available in relation to current loads and modes of operation. The specific power consumption at nominal system performance (payload, throughput…) is not a sufficient indicator. There are no standards available for measuring and calculating characteristic energy indicators (EI) for material flow systems (MFS).

As a basis for the approach of the energy efficiency indicator, the general definition of the efficiency of the EU Directive 2006/32/EC is used.

In order to evaluate the energy efficiency of MFS the respective Output (logistical performances) is specified. Thus, a specific energy demand, based on the logistic performance, is available and as a result different MFS structures are comparable. Characteristic values for energy efficiency of individual devices of the material flow system could be investigated. Scientific and neutral basics were thus developed to evaluate the energy efficiency (EE) of material flow systems, regardless of manufacturer technology.

An essential part of this work is the definition and specification of a holistic EE structure. Efficiency is generally specified by output/input of a process.

$$\eta = \frac{Output}{Input} \tag{1}$$

For energy efficiency $E_{eff}$ of MFS this definition is expanded and specified by the ratio of the output (logistic performance, depending on the device) to the energy consumption, as input.

$$E_{eff} = \frac{Output\ of\ a\ performance\ or\ process}{Input\ of\ Energy} \tag{2}$$

In order to determine, or respectively to measure, the characteristic parameters (output, input) a representative load collective must be specified. It is composed of typical operating states,

- Nominal operation,
- Partial load (turndown),
- No load (idle),
- Stoppage (standby).

These reference loads are combined for standardized representative operation cycles (ROC). They are commonly used for the calculation and dimensioning of material handling components, e.g. hoisting devices or other standardized mechanism groups.

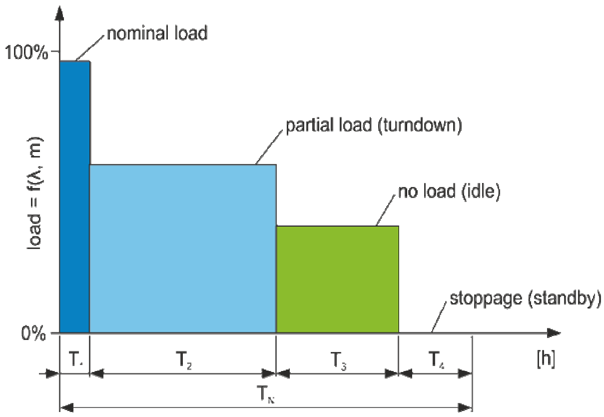



**Figure 3. General Representative Operation Cycle (ROC)**

Figure 3 shows the general approach of represen– tative operation cycles (ROC) for MFS. In the next subchapter (2.4) more detailed ROC-approaches for conveyor and storage systems are specified.

The total duration (reference period) of the ROC is defined by $T_N$. The time units $T_i$ are calculated from the operating states using the relative percentage of time $t_i$.

$$T_i = t_i \cdot T_N \,. \tag{3}$$

Different throughput rates, corresponding to the respective load conditions of the ROC, are considered via the weighting $\lambda_i$ in percent. The sub-cycle related throughputs $\Lambda_i$ are calculated as follows

$$\Lambda_i = \lambda_i \cdot \Lambda_N \,. \tag{4}$$

This approach can be applied to the determination of the energy consumption. With the given conditions the energy demand can be determined by specified basic power measurements and additional calculations. For each state of the representative operation cycle (ROC) the average power $P_i$ must be measured. Multiplying these values $P_i$ with the corresponding percentage of time $T_i$, from the load spectrum, results in the energy input $E_{In}$ (5). This energy demand is specific to the investigated device and indicates the quantity of energy which is necessary to fulfill the material handling function, based on the given ROC.

$$\begin{aligned} E_{In} &= \sum_{i=1}^{n} P_i \cdot T_i = P_1 \cdot T_1 + P_2 \cdot T_2 + \cdots + P_n \cdot T_n = \\ &= T_N \cdot \sum_{i=1}^{n} P_i \cdot t_i \qquad [Ws, kWh] \end{aligned} \tag{5}$$

## 2.4 Energy Indicator (EI) system

In technical applications, indicators are commonly used as specific values. These usually relate a basic input-parameter of a process to a reference output-value. In case of logistics engineering, the "logistic performance" as output-reference is recommended.

The specific energy demand, as the energy indicator (EI), refers the input of energy to the "logistic performance" as follows

$$\text{EI:} \quad e_X = \frac{1}{E_{eff}} = \frac{E_{In}}{W_L} \,. \tag{6}$$

$e_X$ …Specific energy demand of process "X"
$E_{In}$ …Energy input
$W_L$ …Logistic performance (process output)

### Energy Indicator for Conveyor Systems

The energy indicator (EI) approach for conveyor systems was first introduced at MHCL12 [9].

The logistic performance $W_L$ is the product of the number of transported units and the conveying distance $L_F$ in the reference period. This results in the EI for conveyor systems

$$e_{C/(LU,s)} = \frac{E_{In}}{W_L} = \frac{\sum_{i=1}^{n} P_i \cdot t_i}{\Lambda_N \cdot L_F \cdot \sum_{i=1}^{n} \lambda_i \cdot t_i} \cdot \left[\frac{Ws}{LU \cdot m}\right] \tag{7}$$

$e_C$ …Specific energy demand of conveying process
$LU$ …Load unit

This (7) allows the useful description of the energy demand, referring to the transportation of one load unit for one meter of distance.

In addition a road capable detailed measurement procedure and method were specified, verified and validated by a test rig for a belt conveyor system [11, 13].

### Energy Indicator for Storage Systems

By merging the number of total inputs and outputs to the number of double cycles, which are performed during a representative operation cycle (ROC), the logistic performance can be specified. This allows the description of the energy demand of the storage system, referred to the number of double cycles that are performed during the ROC.

$$e_{S/(DC)} = \frac{E_{In}}{W_L} = \frac{\sum_{i=1}^{n} P_i \cdot t_i}{\sum_{i=1}^{n} \Lambda_i \cdot t_i} \cdot \left[\frac{Ws}{LU}\right] \tag{8}$$

$e_S$ …Specific energy demand of storage process
$DC$ …Double cycle

Caused by the differing functional structures of storage systems (ASRS, shuttle or carousel systems) there is a higher complexity to specify comparable representative operation cycles (ROC). For ASRS standards are available (VDI 3591, FEM 9.851). During the effMFS project we investigated comparable ROC for shuttle and carousel systems, based on a distance equivalent approach [14].

Table 1 contains the coefficients, which specify on an exemplary basis the respective parameters of the representative operation cycle for storage systems for double cycles. Some of the table arrays are unused (-), because they are irrelevant for storage process, in opposite to conveying process [11].

**Table 1. Specific coefficients of representative operation cycle (ROC) for storage systems (suggestion)**

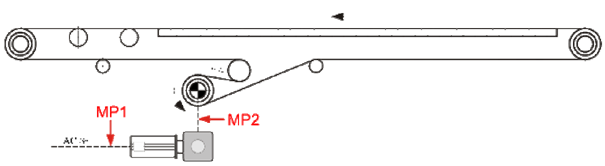
| i | Operation state | Coefficients referred to $T_N$ (%) | | | |
|---|---|---|---|---|---|
| | | Time-slice | Through-put | Load | Velocity |
| 1 | Nominal load | 20 | 100 | 90 | - |
| 2 | Partial load | 60 | 100 | 50 | - |
| 3 | No load | - | - | - | - |
| 4 | Stoppage (standby) | 20 | - | 0 | - |

## 2.5 Energy optimization of conveyor systems

Within the project we investigated the energy efficiency potentials of three different common conveyor types. The results for flat belt operated (TRF) and drum motor operated conveyors were presented at MHCL12 as well as the specific measurement tasks and methods [9].

Figure 4 illustrates the test arrangement of the third investigated belt conveyor (BF). The partial image (a) shows the test installation and the main component of the measurement system too, which is suitable for power inverter driven motors. The details of the sensors, measurement and evaluation technology of the measurement system and the – in part - highly specific requirements are not presented but referenced to [9]. The schematic structure (b) illustrates the major components of a belt conveyor and the various measurement points for power consumption.

(a)




(b)

**Figure 4. Belt Conveyor (BF) - (a) Picture of test rig including the measurement setup and (b) schematic structure**

All relevant partial losses were determined based on the measuring points (MP1 and MP2). The most important results in terms of efficiency potential are as follows.

Two of the investigated conveyor types (BF and TRF) clearly show that the gear motor units cause the greatest losses in relative terms. This has been suspected but not expected, however, in the proven dominance.

Depending on the specific conveyor lengths, the efficiencies of the gear motors in stationary operation, is in some cases significantly below 50 percent (Figure 6).

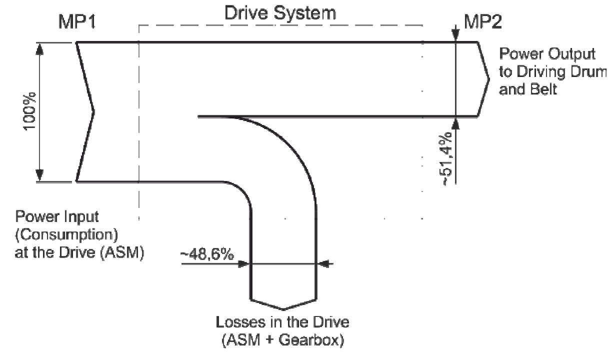



**Figure 5. Typical measurement result on belt conveyor (BF) - power flow diagram in the stationary operating state**

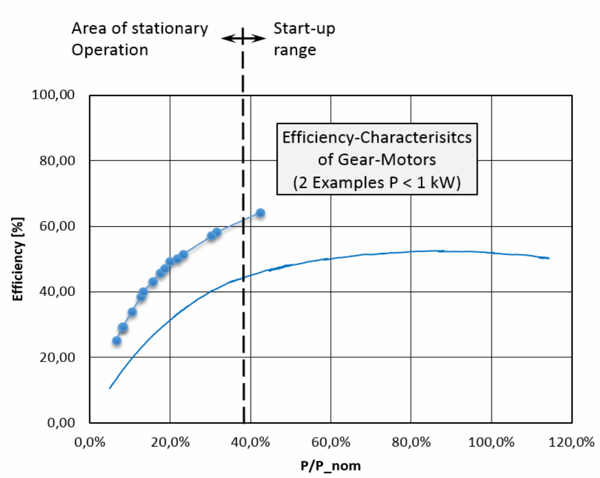



**Figure 6. Efficiency of gear motors – investigated conveyor systems**

The results obtained on the specific test setups can probably be generalized. The reason for this is to be found in the typical efficiency characteristic curves of standard ASM with small nominal power and the use of simple mechanical gearboxes.

As stated in the previous sections of this chapter the highest losses by far in the conveyor types examined (BF and TRF) occur in the gear motor unit. The main reasons can be clearly identified. The basic characteristic for asynchronous motors (ASM) is that they have sinking efficiencies at lower nominal power. In addition the efficiencies of all standard ASM decrease significantly at low load. The same behavior also occurs in the gearboxes in frequent use.

Figure 7 illustrates an optimization approach, the use of special gearless types of motors. Their efficiency profiles could be optimized for part load operating points. The energy saving potential for the stationary operating range shown is up to 50%, depending on the drive concept. It is obvious that an appropriate return on investment and a significant improvement in the life-cycle cost (LCC) can be reached in many applications [12].

Extensive additional studies were carried out to consider the idle and partial load scenarios for conveyors. It was clearly indicated that significant improvements are possible (figure 8).

Figure 8 illustrates the high relative power consumption of conveyors in idle mode as functions of the load. The values of the single conveyor are referenced on the specific nominal load results. The results of an inclined arrangement are also represented (up/down situation) for the belt conveyor (BF). The idle mode power consumption is in the range of from 51% to 92% of nominal load consumption.

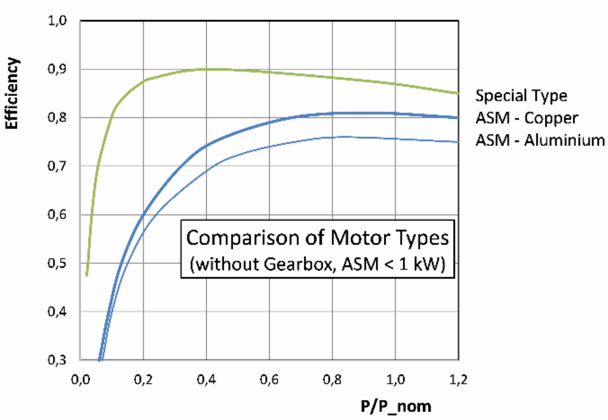



**Figure 7. Efficiency curves - characteristics of different basic motor types (schematic diagram)**

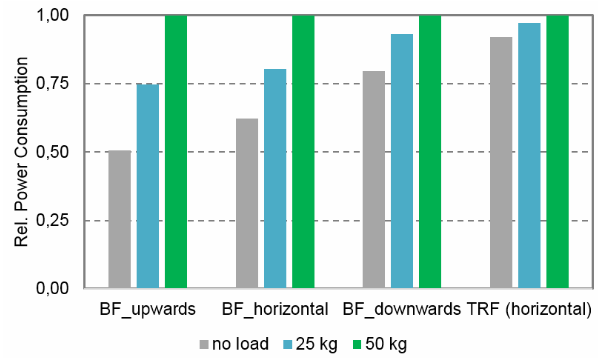



**Figure 8. Relative power consumption of conveyor types – Belt conveyor (BF), Flat belt operated roller conv. (TRF)**

In many conveyor systems only small controller investments should be necessary to be able to stop empty conveyors (sections) consistently. A short amortization time in commercial terms (ROI and LCC) can be expected [12].

These results can again be classified as universally valid, like those of the high efficiency potentials for the small sized ASM previously referred to.

### 2.6 Outlook on further investigations

As mentioned in the introduction, we started a follow-up project to extend the real operation research results in April 2015. The project Energy Efficiency in complex Material Flow Systems (EEkMFS) extends the field of interest in two directions.

First, we will extend the approach of the energy indicator system from device level (chapter 2.4) to process level. The specified use case is a distribution center (figure 1 and 2).

Second, based on the proven high improvement potential for electric drive systems, we will work out a comprehensive drive efficiency calculator model. The goal is the ability to calculate the optimal drive concept in relation to the specific representative operation cycle (ROC) of the specific MFS device.

For an efficiency-optimized type selection and dimensioning of drive systems, it is essential that the individual components have efficiency characteristics in dependence on torque and speed situations. The optimized drive system can be found only by taking the representative dynamic load situations into account.

Therefore the missing basics will be processed by the use of two test rigs. This will be done in close coordination with the industrial project partners SSI Schäfer PEEM GmbH and SEW EURODRIVE GmbH & CoKG. The first test installation (figure 9) will be designed to establish the verified ROC and dynamic behavior of the specific MFS devices. The second one (figure 10) supports the investigation of the characteristic efficiency curves (see figure 7) of typical specific drive concepts. We had to learn here that the nominal IE-class (IE2, IE3 …) of the single motors (without gearboxes and power converters) is absolutely not representative. Additional investigations will be carried out at the Anton Paar GmbH distribution center.

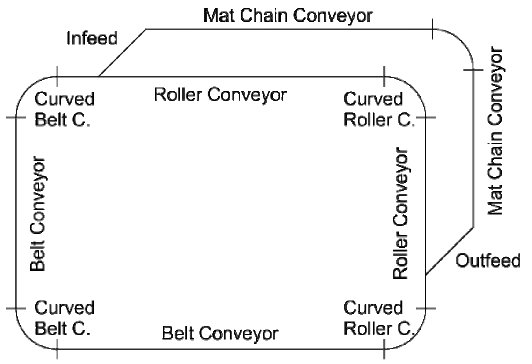



**Figure 9. Testing cycle for different devices (schematic structure)**

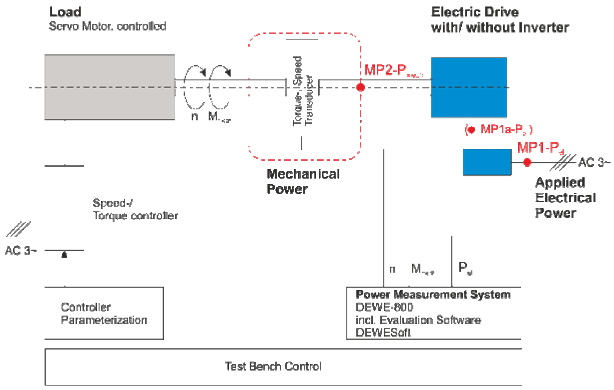



**Figure 10. Test bench characteristic efficiency curves (layout)**

## 3. CONCLUSION

We worked out a general approach by focusing on the overall energy efficiency (OEE) of complex material flow systems (MFS).

First we discussed aspects of system boundary, modularization and classification of subsystems. Then we focused on a basic energy indicator (EI) system, showing the approaches for conveyors and storage devices.

We also carried out measurements of the energy losses of conveyor systems. It is a clearly demonstrated and generally valid fact that there are enormous potentials to improve the energy efficiency based on optimization of electric drive units. We discovered that the standardized IE-class (IE2, IE3 …) of the single motors (without gearboxes and power converters) is not representative. In addition significant energy saving is also possible by means of thoroughly controlled operation modes to avoid idle running as well as to reduce partial load operation.

As a direct result of the evident high potential for energy efficiency improvements for the drive concepts as designed/used, we decided to start a new follow-up research project. We will here investigate the available device concepts by consideration of the most relevant representative operation cycles for the specific MFS. Furthermore a valid model for a MFS energy efficiency calculator will be developed.

We welcome any feedback on these issues!


## ACKNOWLEDGMENT

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## СИСТЕМИ ИНТРАЛОГИСТИКЕ - ОПТИМИЗАЦИЈА ЕНЕРГЕТСКЕ ЕФИКАСНОСТИ


**Н. Хафнер, Ф. Лотерсбергер**



Системи токова материјала су основне компоненте система интралогистике. Оптимизација њихове енергетске ефикасности све више добија на значају. У Институту за техничку логистику у Грацу спроведено је истраживање у трајању од 36 месеци, које је завршено 2014. године. Приказују се резултати истраживања обављених у две главне области. Прва кључна област је уопштени приступ енергетској ефикасности и показатељима енергије. Параметри система транспортера и аутоматског складишних система приказани су у појединостима. Специфичне потребе и структура репрезентативних радних циклуса су поткрепљени илустрацијама.

Други главни циљ истраживања је прикупљање валидних могућности оптимизације уобичајених типова система транспортера. Показано је да постоји огроман потенцијал за повећање ефикасности, који је базиран на електричним машинама. Најзад, приказују се будућа истраживања у трајању од 36 месеци која ће бити проширена на верификоване резултате.