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EQUIPMENT PRESELECTION FOR INTEGRATED DESIGN OF MATERIALS HANDLING SYSTEMS

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Abstract: There is no universal solution method for the design of materials handling systems, which can be applied in all of the system varieties. Probably the best method is the using of an integrated design process, but it can also be problematic in certain cases. In this paper I show a new design concept which can be easily adapted in a simple or in a complex materials handling system. The first step of the process is a preselection of the devices which enables the selection of the applicable materials handling equipment types. This paper summarizes the available equipment selection methods in the international literature. As the actual task of the research, paper presents the general structure and the main tasks of the preselection, as well as the parameters and the basic task of the design process.
Keywords: materials handling, design methods, integrated design, preselection.

1. Introduction

There are many materials handling machines in all fields of our life. The modern industrial and service processes with high performance requirement cannot be imagined without automated materials handling machines. Design of materials handling machines has secular history. While methods became more precious and technical possibilities significantly changed during the elapsed time, principles of the design tasks are still the same. There are many approved dimensioning methods for the modern materials handling equipment aided by computer software. At certain cases (for example: forklifts etc.) the design process is simplified to a selection-application procedure, because manufacturers offer discrete, well defined types in wide range for all of the tasks from their predefined assortments. Huge materials handling systems (for example: overhead trolleys etc.) can be built from module elements which are previously dimensioned in a production catalogue. If you have an individual task or you can take special environment into consideration, the international literature lists many alternatives to choose.

Regarding the above mentioned facts we can say that the design of an individual materials handling equipment for a well-defined task is easily solved by the available dimensioning methods, product catalogues or design software. However in the real, advanced production processes using of individual machines is very rear, so during the design of the materials handling system the adaptation and harmonization of the equipment have to be even solved. As in industrial materials handling systems the selection of the machines cannot be independent from other system elements, so in these cases integrated materials handling design process have to be actualized. Without this approaching the effectiveness of the serving system can be very low.

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2. Design of materials handling systems

Materials handling system design is required if more individual devices or a complex handling system have to be used for the realization of the materials handling tasks. These systems in generally combine the operation characteristics of the used machines, which can be modified through the integration and in certain cases new parameters can be appeared.

During the design of a materials handling system we are looking for serving equipments for a complex materials handling task and synchronizing their operation. The solution can be task-based or system-based approaching. Task-based approaching uses individual materials handling tasks (for example: device selection, route design, etc.) during the design process, system-based approaching analyses the whole system and the relations of the system elements [1], and tries to find similarities with other systems. This method requires the definition of typical materials handling systems [2].

The task-based approaching is much more published in the international literature, its important advantages are the using of real material flow parameters and better mathematic description. Design based on task-based approaching has four main subtasks:

A) Design of the allocation of the materials handling objects
B) Selection and dimensioning of materials handling devices
C) Design of unit loads
D) Scheduling of the materials handling tasks

In the literature authors in generally deal with only one subtask. For example *Felföldi* [3] in 1969 defined the design of materials handling system as three following steps (C, A and B) independently of the scheduling of the equipment. *Yaman* [4] in 2001 published an equipment selection method which handles the selection and the allocation subtasks together. *Cselényi et al.* [5] integrated all the four subtasks for route selection of trucks in 2006. *Ioannou* [6] in 2007 published a model which integrates the A, B and D subtasks and gives analytic formula for the optimisation of the design parameters.

If the design subtasks can be solved individually, the design process will be easier because there are many proved specific method [5]. For example: the basic data are the locations of the objects for the equipment selection and equipment parameters define the unit loads. If all of the subtasks have to be solved, then we have to use an integrated materials handling system design. In this case the subtasks can also be actualized individually, however the subtasks effect each other, so an iterative method required. The best process for the design is if we calculate the parameters of the subtasks individually and give the results as constant to the next subtask. At the end of the process we have to go back to the first step and recalculate the parameters. After some round we will find the optimal variation. The order of the subtasks is in generally fix (A, B, C, D), but it can be changed depending on the given design task. The required iteration number is determined by the complexity of the materials handling task. As the result of the design procedure we got an equipment set and an allocation variety which are near the optimal serving solution.

As there are many different materials handling equipment types [7] the characterisations of the systems basically determines the applicable methods and their efficiency. Materials handling design tasks can be ranged in three main group (Table 1) in the aspect of the efficiency of the solution methods: simple, multiple and complex tasks.

Table 1

Characterisation of the materials handling design tasks

Parameter	**Materials handling design tasks**		
	simple	***multiple***	***complex***
1. Equipment type	one	some	many
2. Quantity of equipment	low	large	large
3. Material flow	deterministic	deterministic, or near deterministic	stochastic
4. Relation	direct	direct	direct, or indirect
5. Allocation	linear	linear, or marginally parallel	parallel

Design task is simple if it requires only one materials handling equipment type (usually with a few machines), the characteristic of the material flow is deterministic and the relations among the objects are direct and linear.

Design task is multiple if it requires some materials handling equipment types (but usually with numerous machines), the characteristic of the material flow is near deterministic and the relations among the objects can be marginally parallel.

Design task is complex if it requires many materials handling equipment types with numerous machines, the characteristic of the material flow is stochastic and the relations among the objects are parallel. The larger the number of the parameters have to be taken into consideration, the higher is the complexity level of the system and the harder is to find optimal solution.

The above mentioned design scheme can be applied easily and efficiency at multiple materials handling tasks. At simple design tasks equipment selection is usually based on practical experiences because using of the design methods are more complicated. At complex materials handling systems the determination of the required parameters can cause problems because of the high number of device types. In this cases the solvability requires the reduction of the parameters (design actualised on certain varieties), but it can also reduce the efficiency of the design process (local optimum). In generally at complex tasks, the searching for the optimal solution requires the using of heuristic methods [8].

There is a better situation if the design process is not full so only one subtasks have to be solved. In this case the result depends only the applied method selected form the literature, but one problem is appearing: the designed system will be optimal only in the aspect of the given subtask.

Based on the above mentioned contexture we can say that exists usable design scheme for the materials handling tasks but it cannot be applied in all of the cases because of their complexity. I think there is a needs for a universal design scheme which can be applied in all of the materials handling systems. This method have to be general, easy adaptable and efficient for simple and multiple tasks and can give suitable initial versions for heuristic algorithms of complex systems.

3. New design concept

One of the most important causes of the problems of integrated materials handling design that the selection and the dimensioning of the equipment are treated as one element. This concept is acceptable in the aspect of the practice because they are coherent, but it requires that all of the design steps have to be actualized on all of the possible machines.

In my research, I proposed a new design concept which can help to eliminate the above mentioned problems. In the new design method I separate the selection and the dimensioning parts (Figure 1), in the first step I make a preselection for the main equipment types and in the third phase the selected machines can be dimensioned. As a result of this concept the other three subtasks have to be actualised on the selected machines. If the design procedure requires the analysis of more than one equipment types, then the first phase also have to be included in the iteration process.

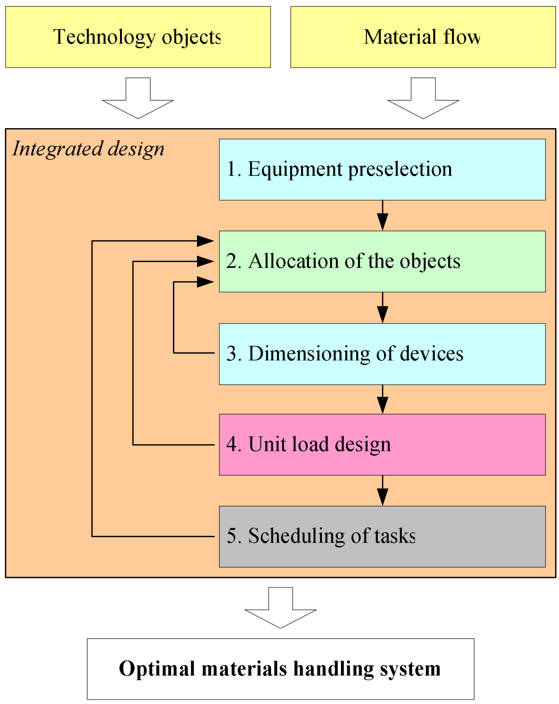

Figure 1. The new, general design concept

Preselection of the equipment means a procedure to determine the principally suitable materials handling machine types based on certain parameters of the tasks and the devices. This phase is the main aim of my research.

The dimensioning phase is served for determining of the required performance and the specialisation of the selected equipment. For this purpose exact dimensioning methods or knowledge-based selection methods can be used.

4. Selection of materials handling equipment – literature review

The equipment selection is one of the basic tasks of the design process of materials handling systems. The aim of it to find a suitable serving device for the related technology objects. Equipment selection methods can be categorized based on *Welgama and Gibson* [9] as analytical methods, knowledge-based methods, hybrid methods.

Analytical methods use mathematical formulas related to a given objective function to find the optimal service equipment. Among the earlier methods *Webster and Reed* [10] and *Hassan et al.* [11] used a cost function as objective function (minimal materials handling cost), but *Hassan et al.* took also the capacity utilization into account.

The most important problem of analytical methods is the using of limited objective function (usually only one), thus the effects of other characterisations are neglected, which makes practical applications more difficult.

Knowledge-based methods use a special database of practical experts which included their knowledge about materials handling equipment. These methods look for results by the comparison of the material flow and handling device parameters and use computer software for the selection. There are many knowledge-based selection methods in the international literature (universal and also device specific).

One of the first knowledge-based methods published by *Malmberg et al.* [12] for selection of trucks (PROLOG). A general method (MHES) was described by *Hosni* [13] in 1989 which analysed 11 parameters and 5 equipment types. The method (MATHES) of *Fischer et al.* [14] uses 22 machines and discrete scales (2–5 value/parameter) for the material flow parameters. *Matson et al.* [15] developed a selection method (EXCITE) for the serving of individual part manufacturing processes. The method of *Park* [16] was suitable also for the selection of storing devices and warehouse equipment (ICMESE). *Yaman* [4] in 2001 published a new concept for the equipment selection, he integrated the selection and object allocation subtasks. *Kulak* [17] in 2005 applied the Fuzzy-logic at first in the equipment selection process (FUMAHES).

Beside the general equipment selection methods, there are many device-specific solutions which are dealing with only one materials handling machine type. Among others, various authors published selection methods for bulk solids handling devices *(Velury and Kennedy)* [18], for AGVs *(Luxhoj et al.)* [19], for industrial robots (*Shashikumar et al.)* [20], for conveyors *(Fonseca et al.)* [21] etc. The application possibilities of these device-specific methods are limited, but they enable deeper and more precious design processes.

Disadvantages of knowledge-based methods are that they limit the parameter types (only for the given material flow parameters) and disable the system approaching [22].

Hybrid selection methods use a knowledge-based procedure and an analytic formula together to select the optimal materials handling solution. *Gabbert and Brown* [23] published one of the first hybrid equipment selection method in 1989. *Welgama and Gibson* [9] combined a cost based analytical method with a knowledge-based procedure and took also the aisle space into consideration. *Chan et al.* [24] applied a selection hierarchy during the design and was able to analyse more aspects than their predecessors (for example: technical specialities, strategically aspects etc.). *Mirhosseyni and Webb* [25] published a hybrid method in 2009 which used Fuzzy-logic for the knowledge-based procedure and Genetic Algorithm for the selection.

Hybrid equipment selection methods offer an overall solution for materials handling devices using a knowledge-based procedure and an analytic optimisation process. Their most important disadvantage is the one objective function (in generally the minimum of the materials handling cost) which cannot enable to take other objective functions into account. Beside it, the high complexity of the hybrid methods makes the practical applicability harder.

5. Principles of the equipment preselection

Obvious possibility is to use simpler knowledge-based selection methods for the preselection, however there is some problem. The principle of the knowledge-based selection procedures is the general solution search in which they combine the selection and the dimensioning. Because of this approaching these methods cannot be adapted into the preselection. *Yaman* [4] was the only one who used two steps within the design process (selection and detailed design), but he also did not separate the parameters.

Another specification of the knowledge-based methods is that they use a predefined algorithm with discrete steps for the design. It is also cannot be applied in the preselection, because the simplified comparison lets the using of an analytical process based on numerical parameter values.

Common principle of the equipment selection methods that they try to involve more and more parameters into the design process. It is an understandable effort to make universal methods, but it results less embraceable procedures. This black-box effect sometimes deters the practical users from the application of these methods as they cannot see into the design procedures and cannot estimate the adequacy of the results.

During my research I use another approaching: I define a simple design task which can be described by some basic parameters and try to find an analytic method to select the suitable equipment. This method is not applicable for the general design process however it is suitable for preselection of the machine types. Later, in a future phase of the research the base task can be extend and more complex tasks can be also taken into account.

To define the base materials handling task we have to define a simple material flow relation (Figure 2.) and its parameters, which can be:

- unit parameters (size, mass, handling possibilities etc.),
- transport parameters (locations, routes etc.),
- time parameters (duration, seasons etc.).

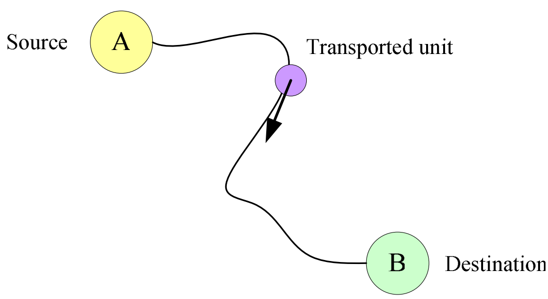

Figure 2. Base material flow scheme

Characterisations of the materials handling tasks can be practically separated into three groups (Table 2) in the aspect of the design: material flow parameters, restrictive parameters, device parameters.

Table 2

Parameters of materials handling tasks

Material flow parameters	**Restrictive parameters**	**Device parameters**
1. source location	1. objects restrictions	1. capacity
2. destination	2. road restrictions	2. operation character
3. goods type	3. goods restrictions	3. track lines
4. quantity	4. service method	4. velocity
5. service times		5. handling methods

Material flow parameters are determined by the materials handling task and served for the describing of the materials handling processes. Restrictive parameters are usually not depend on the material flow tasks and they do not change during the service process. Device parameters define the specifications of the materials handling equipment and limit their applicability. The above mentioned three parameter types have different roles in the equipment selection procedure: material flow parameters defines the task, restrictive parameters stand limits for the possibilities and device parameters determines the solution method (Figure 3).

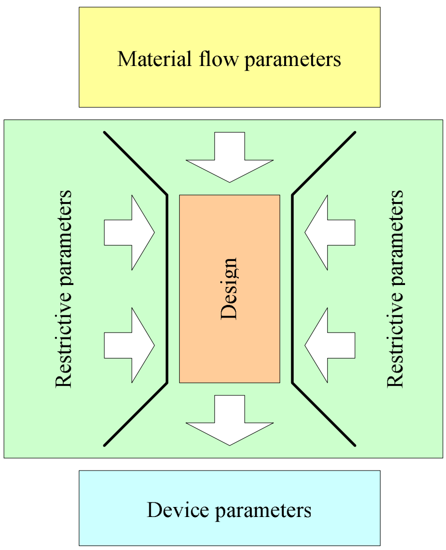

Figure 3. Relation of the parameters and the equipment selection procedure

There is an important aspect for the equipment preselection that the suitable device types can be determined by an analytical procedure based on numerical parameter values. In the aspect of properties, design parameters can be categorized into three different groups which are

- numerous parameters,
- parameters can be transformed into numerical form,
- parameters cannot be transformed into numerical form.

As the material flow parameters and the device parameters (except handling methods) can be described with numerical values (Table 3) so their relations can also be defined by an analytical formula. The parameters cannot be transformed into numerical form have to be taken as a restriction (for example: mathematical limits) into consideration (primarily the restrictive parameters).

Table 3

Parameters with numerous values

Material flow parameters	**Device parameters**
1. transport length	1. transport velocity
2. angle of uprising	2. angle of uprising
3. quantity	3. capacity
a) unit loads	a) unit loads
b) quantity/hour	b) quantity/hour
4. service interval	

Parameters with numerous values needs a mathematical function with values in 0-1 interval, which has the value of 1 if the task parameter is near the device parameter. As a first approaching we use the next exponential formula (Figure 4):

$$f = e^{-\gamma \cdot \left| \frac{p_{AB} - p_E}{p_{AB}} \right|^{\delta}} \tag{1}$$

where

p_{AB} – is the required value of the material flow parameter,
p_E – is the characteristic value of the device parameter,
γ – is a coefficient to determine the range of the analysis,
δ – is a coefficient to determine the range of the applicability.

Based on function (1) equipment can be qualified with the next formula:

$$M_E = \frac{\sum_{i=1}^{n} e^{-\gamma_i \cdot \left| \frac{p_{ABi} - \overline{p}_{Ei}}{p_{ABi}} \right|^{\delta_i}} \cdot \beta_i}{n} \tag{2}$$

where

β_i – is the weight coefficient for defining the importance of parameter *i*,
n – is the number of the analysed parameters,
$\overline{p}_{Ei}$ – is the average value of the device parameter *i*,
p_{ABi} – is the required value of the material flow parameter *i*,
γ_i – is a coefficient to determine the analysis range of parameter *i*,
δ_i – is a coefficient to determine the applicability range of parameter *i*.

The higher is the value of M_E for the given equipment, the better fulfils the device the requirements of the task.

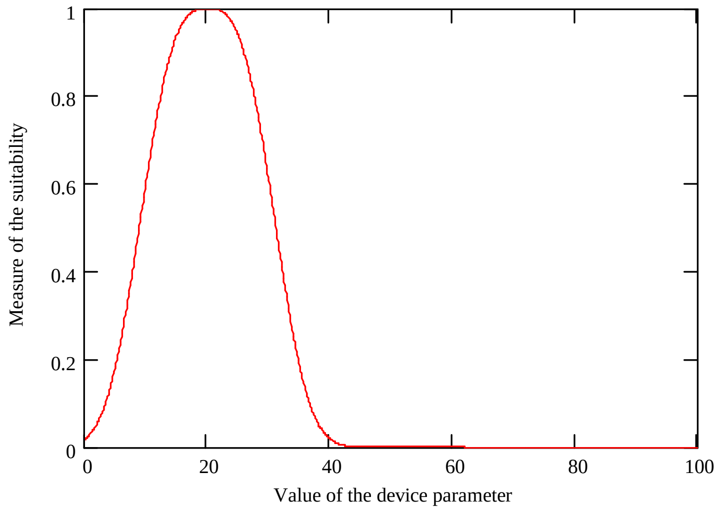

Figure 4. Mathematical function for the preselection

8. Summary

There are different design methods for materials handling systems, but none of them offers universal solution for all of the materials handling tasks. The cause of it that the differences are very large among the system varieties and it is hard to find the optimal solution at complex cases. In this paper a new design concept was presented which can be easily adapted into the simple or also the complex tasks. One of the most important step of the design process is the equipment preselection which enables to select the main materials handling machine types before the other subtasks. The preselection can reduce the complexity and time interval of the design procedure, thus helps to implement the design process into the practice. This paper sketched the general structure, the specification and the most important parameters of the preselection procedure. Beside it the base design task and the base mathematical formula were also described.

Next phase of the research is the analysis of the parameters which cannot be transformed into numerical form, and the determination of their consideration possibilities.

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