Advanced Logistic Systems, Vol. 11, No. 1 (2017) pp. 61–76.

COMPLEXITY ANALYSIS OF MATERIAL HANDLING DESIGN PROCESSES

PÉTER TELEK[1]–CHRISTIAN LANDSCHÜTZER[2]

Abstract: Knowledge Based Engineering systems are advanced, effective techniques which can deliver useful solutions for every field of the industry, and it also has relation to the design of material handling processes. One of these methods, the linked KBE/CAD solution, can be applied for the design of different material handling processes. In this paper we describe a calculation method to determine the complexity level of the material handling systems in the aspect of the design process. Complexity level of a design solution has important role in comparing the individual tasks and methods, and it can help to evaluate the application advantages of linked KBE/CAD solutions.
Keywords: *material handling design, KBE systems, parameter analysis, complexity*

1. INTRODUCTION

Application of knowledge based systems in the design of material handling has more than three decades history, but there are no widely used, general, effective methods so far. Knowledge Based Engineering (KBE) systems are advanced, effective techniques which can deliver useful solutions for every field of the industry (e. g. in the automotive industry), and it also has relation to the design of material handling processes. One of these methods uses the linked KBE/CAD concept which can be suitable for different handling processes.

The design of material handling machines and processes uses many handling parameters during the design procedure, which have significant effects to the complexity of tasks. In this paper we give an overview about their most important categories and describe a calculation method to determine the complexity level of the material handling systems in the aspect of the design process. Complexity level of a design solution has important role in comparing the individual tasks and methods, and it can help to evaluate the application advantages of linked KBE/CAD solutions.

2. KNOWLEDGE BASED ENGINEERING IN MATERIAL HANDLING

Knowledge Base Systems (KBS) are computer programs which use Artifical Intelligence (AI) techniques to solve complex problems based on specific experiences of human experts [1]. KBS methods related to material handling use a special database of practical experts which includes their knowledge about material handling equipment and look for results by the comparison of the material flow and handling device parameters [2]. 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.* [3] for selection of trucks (PROLOG). After the beginning, there were different attempts to develop

[1] PhD., University of Miskolc
alttelek@uni-miskolc.hu
H-3515 Miskolc-Egyetemváros, Hungary
[2] Assoc. Prof. DI Dr. techn., Technical University of Graz
landschuetzer@tugraz.at
Inffeldgasse 25e/IV, 8010 GRAZ, Austria

the simple selection method into optimisation process using special objective functions and analytic algorithms (Hybrid methods, e. g. *Welgama and Gibson* [4]).

Knowledge Based Engineering (KBE) is a technology able to merge the capabilities of conventional Knowledge Base Systems with computer aided analysis and design systems (CAE and CAD systems) [1]. KBE systems enable to insert the result of the knowledge based calculation procedure directly into the design process of machine elements using special software solutions. For the realisation of KBE systems three different solutions were published in the international literature [12]:

- augmented CAD systems with KBE,
- full KBE systems and
- linked KBE/CAD solutions.

Augmented CAD systems with KBE are found in many different CAD environments and have different scopes of operation [5]. Main principle of this concept is that the KBS solution has to be integrated into the CAD environment. Well known commercial products are Knowledge Ware within CATIA and Knowledge Fusion within NX [6]. All approaches together have some common characteristics [7]:

- no full generative modelling and therefore manual adjusting effort,
- no exploitation outside their KBE language and therefore not web-based frameworks,
- lots of editing effort and "unfriendly" scripting languages,
- they only do better donkeywork and are non-reactive to new technologies, etc.

Full KBE systems are object oriented highly advanced generic and super ordinated software programs which apply captured knowledge to design processes by using different visualization tools [8]. The systems must drive the way of design automatically by using various validation rules and should not criticize pre-generated results leading towards engineering process automation. Object oriented KBE (e. g. MOKA [9]) now means inheritance from classes of objects and customization of very much unified models, following the classical tree structure [7]. An investment into a full KBE system is nowadays only seen in automotive and aeronautic sectors [10].

Linked KBE/CAD solutions means a new approach, in which existing KBE and CAD solutions are linked by special software. The basic idea behind this concept lies in using separated system elements for knowledge capture and use as well as geometry representation. In its most basic form the two core elements can be a calculation scheme implemented in a capable software tool and a parametric CAD model. In order to combine them to a full featured application they are bidirectional interconnected to each other via a specialized interface [11].

What KBE means within Material Handling Equipment Design (MHED) is best described in [7]. The first is to specify input parameters in form of rules and constraints classes for KBE in MHED. Some fuzzy criteria such as shape design, leading to customer acceptance or not, and system integration are relevant as well as the "harder" facts concerning manufacturing and costs, which can be formulated within rules much more easy. As every MHE is determined by the demands of throughput (in tons or pieces per hour) it is necessary, to define throughput as the major input parameter [7].

All other classes derive directly therefrom as especially all rules and constraints for design and engineering/sizing. Therein standards have to be considered as well as know-how of employees for i.e. variant management using carry-over-parts to reduce costs and stock for production. Taking all those input together leads to a KBE system of whatever environment, containing a set of rules and constraints settled around the BOM (Bill of Materials) and its underlying product structure. Key feature is the reliable function of the partly automated design, providing the designer with additional information for geometry design. There he gets information about minimal sizes resulting from stress calculations, information about useable space and interface connections all from as less as possible input parameters (throughput, storage capacity, etc.) [7].

Having in mind, that this approach is settled around augmented CAD KBE systems it's not the main objective, to get fully automated design with generative modeling. Also the knowledge reuse is limited, as many of the rules have to be written in CAD scripting language without export functions. Altogether leads to major improvements in the design workflow for MHED and last but not least to better products with less development effort and better cost awareness [7].

To make KBE successful it's necessary, as a key result of literature review, to differ between the various degrees of automation in design work. Design work in material handling is completely different if one has to design a wire-rope drum or if one has to layout a complete storage system [12]. There are certain tasks more or less predestinated for KBE so that with a determination that reflects this degree of automation we can talk about KBx [12], which can be Knowledge Based Engineering (KBE), Knowledge Based System Design (KBSD) and Knowledge Based Layouting (KBL).

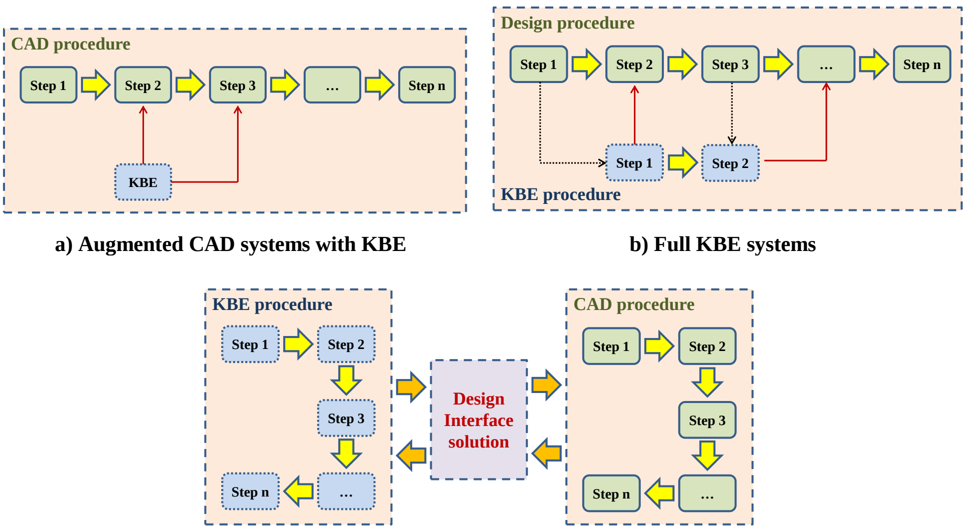
Different KBx has very different scope of use, functions, powering knowledge and application *(Table I)*. The manifestation of automated design in KBx needs a clear database, interconnections and goals for varying applications [12].

Table I.
KBx definitions based on [12]

	KBx Knowledge-based engineering approaches at different detail design levels		
Scope of automated engineering	**KBE** Knowledge-Based Engineering	**KBSD** Knowledge-Based System Design	**KBL** Knowledge-Based Layouting
	Components, parts, machines	*Machines and systems*	*Systems*
Functions	Full automated (detail) design of parts and subassemblies	Full automated master and layout design of assemblies and systems, specifications of machinery	Full automated layouting of systems, specification of systems
Use for	– customizing machinery – tailored products – product families	– dimensioning motors – defining interfaces – CAD top-down design – CAE models	– space requirements – early cost estimation (bidding) – draft bill of material
CAD domain	*detail geometry models*	*reduced geometry for CAE*	*shrink wrap geometry for layout*
Data, information and knowledge sources	– standards, best practice – production facilities – manufacturer data – engineering theory	– standards, best practice – supplier and engine data – engineering and mechanics theory	– standards, best practice – manufacturer data – customer rel. management – logistics theory
	Material flow calculation (throughput, capacity)		

3. Structure and operation of KBE methods in material handling

Different KBE solutions have different structures, elements and methods which effect the operation characteristics and the applicability in practice. Structure and relations of KBE at the different methods can be seen in *Figure 1*.



a) Augmented CAD systems with KBE **b) Full KBE systems**

c) Linked KBE/CAD solutions

Figure 1. Structures of KBE solutions

In augmented CAD systems with KBE, the role of KBE is minor and the task of it is to determine certain parameters required by the CAD procedure (see *Figure 1/a*). In this case KBE element is linked to a few process elements and the relation exists only in one direction. Full KBE systems contain only one main process, so KBE solutions are integrated deeply to the design procedure (see *Figure 1/b*). It means that the KBE process is parallel to the main design procedure and all the KBE elements have two-direction relations to different design elements. At linked KBE/CAD solutions CAD and KBE procedures are independent each other, only the Design Interface software connects them during certain phases of the design process (see *Figure 1/c*). Main task of the Design Interface is to enable a bidirectional communication for the exchange of parameters, as well as the extraction of visualization and analyzation data (e. g. images, non-parametric geometry and bill of material) of the CAD model [11].

As it can be observed on *Figure 1*, relations among the different elements of the design process have very important role in the applicability of KBE methods. These relations involve mainly the exchange of data required by the given process steps in all of KBE solutions, which data is linked to certain parameters of the designed systems.

In KBE methods for the design of material handling, parameters used in the process appear in different parts of the related process elements. To determine the role and effects of the parameters in the design procedure, we have to describe the main types and characterisations of them.

4. MATERIAL HANDLING PARAMETERS

During the design of material handling we search for solution for one and more material handling tasks. The tasks and also the solutions can be very different depend on many factors, but the realization scheme is the same: the parameters of a task and a solution have to be fitted. The problem is that the parameters of a material handling system are not exactly defined for all the tasks, because they depend on many factors. If we could define, determine and allocate all the required parameters for the design procedure, results of the design process can be better and easily achieved.

There are many parameters, data, characterisation and influencing factors in material handling processes used for different purposes. If we want to make an overview about the most important parameters, we must put them into different categories. Apple [13] defined 4 main categories of influencing parameters for the process analysis of material handling, which were divided into further subcategories (Figure 2):

1. Parameters related to material
2. Parameters related to movement
3. Parameters related to method
4. Parameters related to physical restrictions

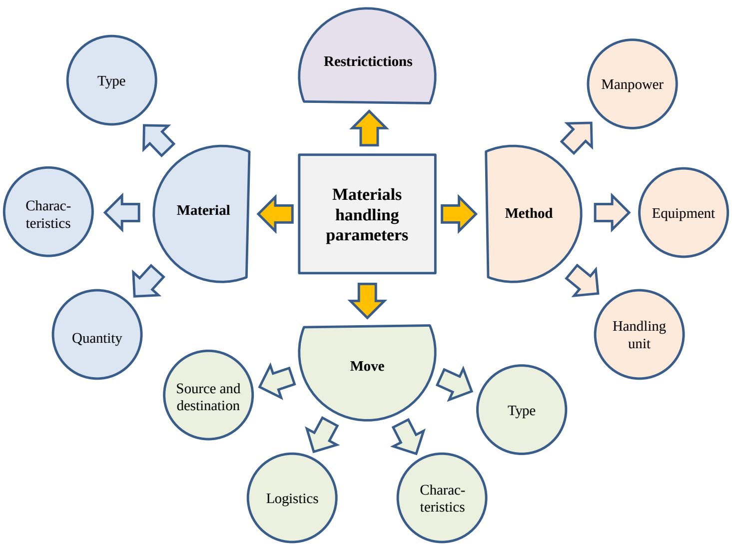


Figure 2. Material handling factors based on [13]

Goods have three different factor-types effecting to the handling process: type, characteristics and quantity (see *Figure 2*). Type can be unit, bulk, liquid or gas [13]. Characteristics of the material have many aspects from geometric data to the handling specifications, depend on the type and behaviour of the goods. It is hard to give short overview about them, but the international literature presents many details in different approaches (see [14]). Quantity of the material basically determines the handling process and can be in different dimensions (kg, m^3, pieces, etc.). Calculations of the material handling process requires material flow data in generally, especially the material flow intensity (in kg/s, pcs/h, etc. – see [15]).

Movement parameters of a handling process can also be grouped into four main categories: source and destination, logistics, characteristics and type [13]. Sources, destinations (manufacturing objects, stores, etc.) and their relations determine the transport routes and the scope of the moving. Logistics defines the level and range of the material handling activities (internal, external, etc.). Characteristics of the movement involve all moving parameters (speed, distance, frequency, etc.) and environment conditions. Type of the movement can be transporting, conveying, transferring, loading, etc. Material handling method can be manual solution (handling at workplaces, in stores, etc.) or use of handling equipment (manually controlled or automated, continuous or discontinuous) and depends on the unit used for handling (pieces, palettes, boxes, containers, etc.) [13]. Parameters belonging to the movement method involve all the machine and unit parameters. Restrictions contain all parameters which limit for the application of possible solutions and influence the design process [13]. They can be physical restrictions, operation limits, applying problems, etc.

Different parameters have different roles in the design of the material handling, so to analyse their effects another approach has to be applied. The main concept of the design process is that we have to determine the parameters of the applied solution based on the parameters of the handling task. In the aspect of this design concept, parameters can be categorized into three groups [2] *(Figure 3)*:

1. Parameters of the handling task
2. Parameters of the applied solution
3. Influencing parameters

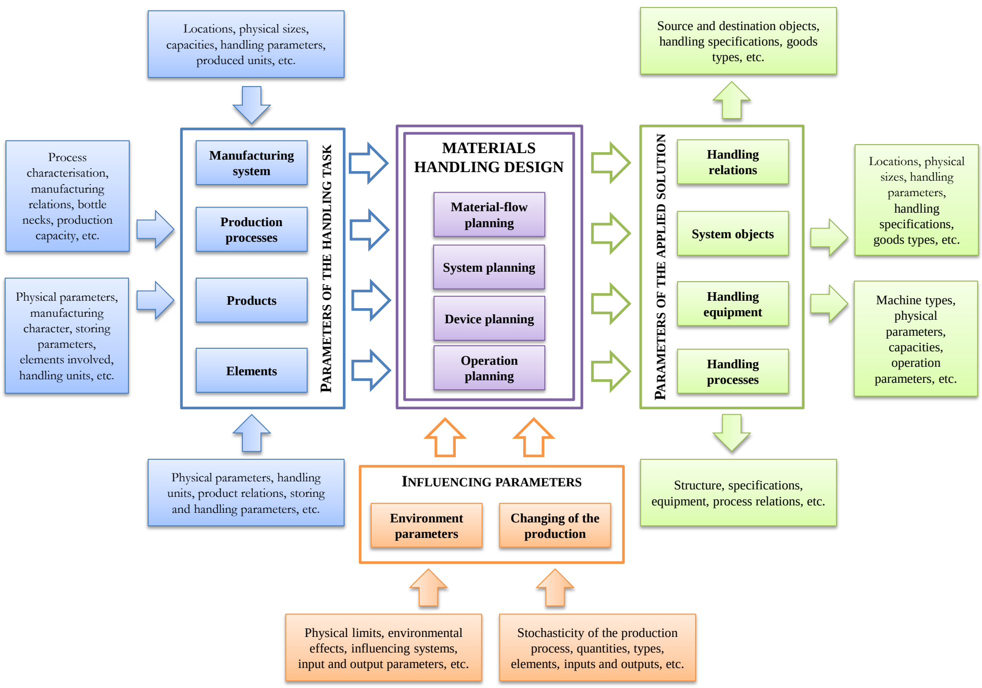


Figure 3. Role of the parameters in the design process of material handling

Parameters of the handling tasks are calculated based on the related manufacturing or service process steps and can be applied for description of the material handling process. Parameters of the applied solution define the specifications of the material handling equipment and limit its applicability. Influencing parameters are usually not depending on the material handling process, but they have many effects on it.

Different handling processes require different design methods, so the actual set of parameters used in a design process is also different. It means that all the design tasks and methods use a determined set of parameters. Of course, this is evident for the individual planning solutions (e. g. location planning, device-planning), but it can be problematic for complex, large-scale design processes.

This is especially true for KBE systems, where two or more really different design processes have to be suited. If we can exactly separate and determine the required parameters for the individual design elements, the process can be much more effective and the complexity level can also be reduced.

5. Effects of handling parameters to the complexity of the design

Design of material handling systems is not a simple task, there are many methods for the selection of the different equipment and to determine the details of the material flow tasks, but none of them can give a generally applicable, effective solution. The most problematic point is the large deviation between the different devices and the material handling tasks [16].

The design solution can be task-based or system-based approaching. The task-based approach uses individual material handling tasks *(Figure 4)* during the design process, system-based approaching analyses the whole system and the relations of the system elements [17] and tries to find similarities with other systems. The task-based approaching is much more published in the international literature (e. g. [18]), its important advantages are the use of real material flow parameters and better mathematic description.

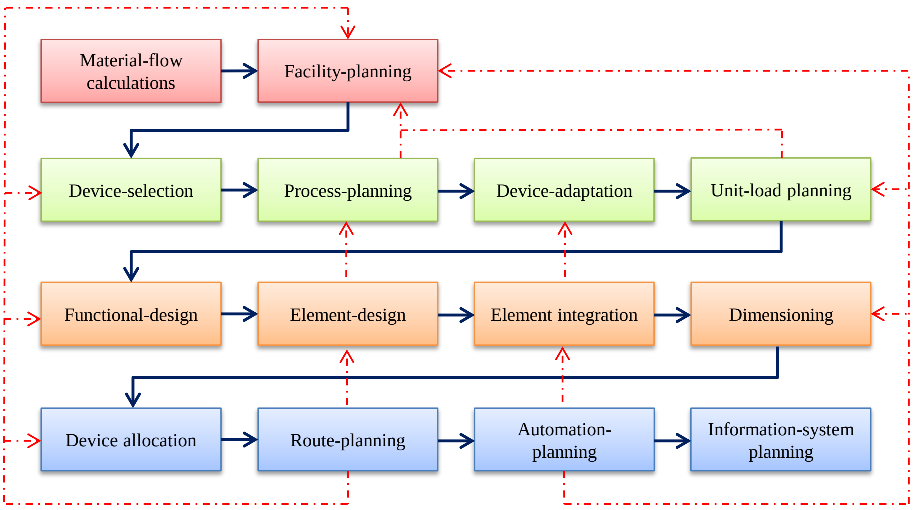


Figure 4. Design elements used in task-based approaching

Design tasks used in task-based approaching can be solved as an integrated process, as an individual task or as a combined solution.

If all the tasks must be solved during the design, then we must use an integrated design process [19]. In this case, all the tasks can be actualized individually; but every task effects each other, so an iterative method is required. The iteration number is determined by the complexity of the material handling tasks (it can be huge in complex cases). As the result of the design procedure we have got an equipment set and an allocation variation, which are near the optimal handling solution.

If the design tasks can be solved individually, the design process will be easier, because many proved specific method can be used [2], but a problem is appearing: the result will only be optimal in the aspect of the given task. Combined solutions mix the specifications of the integrated and the individual design, but they can be very different [11]. This concept involves at least two design tasks, which have to be realized together.

Complexity of material handling design processes depends on different factors, but the most important are:

- number of the involved design tasks,
- number of the parameters taken into account,
- number of the system elements,
- complexity of the relations among the system elements, etc.

All influencing factors have special effect to the design process, however the applied design tasks, the number and relations of the system elements are determined by the given handling process, so it cannot be influenced generally. Of course, many solutions are existing to optimize the design processes in the aspect of the above-mentioned factors [e. g. 20], but it is out of the scope of our paper.

Our research idea is to reduce the complexity of the design processes depending on the parameter-structure and -relations. To reach this objective we must analyse the influencing parameters of the handling process. If we can determine relations and direct influencing effects among the different parameters, we can reduce the complexity level of the material handling design processes.

5.1. Analysis of the parameter structure of handling processes

Complexity is one of the most important description parameters of large, complex systems, which can help to understand and solve their design and operation tasks. It is especially true for technical systems, where complexity has significant role [21].

Individual design tasks use given set of handling parameters, which is suited to the task and its specifications. Based on the number of the parameters in the set, we can define a complexity level for the design process. This complexity level cannot describe the characterisation of the design process, because the other influencing factors are also required, however it can give information about the complexity of the task, which can help to compare the individual tasks and methods.

For example, if we must use two design methods to solve a given handling task, and we know how many parameters are applied by the individual methods during the solution, we can calculate the complexity level of them. If both methods give the same results, the better will be what uses the simpler process. The lower the complexity level of a design method, the simpler will be the way which can be applied for the calculations.

Complexity level of a design task *(C_{task})* can be calculated based on the number of the parameters which can be taken during the process into consideration and the quantity of the system elements involved in the task:

$$C_{task} = \frac{\sum_{i=1}^{N} n_i^{f_i} \cdot p_i}{R_{st}} \qquad (1)$$

where

N – number of parameter groups related to the material handling system,
p_i – number of parameters in parameter group i,
n_i – number of system elements for which the parameters of parameter group i are valid,
f_i – object coefficient related to the number of system elements for which the parameters of parameter group i are valid,
R_{st} – reference number containing the total number of the parameters related to the material handling system.

Object coefficients *(f_i)* used in (1) are depending on the number of the objects, elements, parts, etc. of the system and take the effects of the numerosity into consideration (the higher the number of the elements, the smaller the effects of one element to the complexity will be). Reference number *(R_{st})* defines a base to compare the individual tasks of a given system, its value is the total number of the parameters in the analysed system.

Based on *Figure 3*, we can describe all parameters which influence the material handling system. Naturally, the number of the parameter groups and its elements depend on the given system, we listed the most important parameters in *Table II*, which also presents the minimal value of the reference number (R_{st}) for this case.

If we actualize equation (1) for a given task and for the whole integrated design process, we can compare the complexity levels of them.

In case of integrated design, we can take all the parameters into consideration, so the complexity of the production process *(C_P)*, the influencing factors *(C_I)* and the handling process *(C_H)* can be calculated as

$$C_P = n_{mo}^{f_{mo}} \cdot p_{mp} + p_{pp} + n_p^{f_p} \cdot p_p + n_e^{f_e} \cdot p_e \qquad (2)$$

$$C_I = p_{ep} + p_{cp} \qquad (3)$$

$$C_H = n_{hr}^{f_{hr}} \cdot p_{hr} + n_{hs}^{f_{hs}} \cdot p_{hs} + n_{he}^{f_{he}} \cdot p_{he} + p_{hp} \qquad (4)$$

$$C_{task} = C_M + C_I + C_H \qquad (5)$$

where

f_{mo} – object coefficients for the manufacturing objects,
f_p – object coefficients for the products,
f_e – object coefficients for the elements,
f_{hr} – object coefficients for the handling relations,
f_{hs} – object coefficients for the handling system objects,
f_{he} – object coefficients for the handling equipment,
other parameters are involved in *Table II*.

Table II.
Parameters influence the material handling systems

PARAMETER TYPES	**Number of system elements**		**Number of parameters**	
	Type	***Variable***	***Variable***	***Value***
A) Production parameters			p_M	**→68+**
1. Manufacturing system	manufacturing objects	n_{mo}	p_{mo}	**→19+**
Object locations (x, y, z)				3
Object sizes (D, W, H)				3
Object capacities (pieces, speed, performance, etc.)				3+
Handling parameters (clutching method, storing possibility, etc.)				2+
Handled unit parameters (sizes, weights, shape, etc.)				5+
Produced units (types, quantities, variations, etc.)				3+
2. Production process parameters			p_{pp}	**→16**
Process (type, times, breaks, relations)				4
Manufacturing relations (relations, sources, destinations, lines, units)				5
Production capacities (available, used and remained capacities, needs)				4
Bottle necks (minimum performance, differences, free capacities)				3
3. Product	products	n_p	p_p	**→18+**
Physical parameters (size, weight, shape)				5
Manufacturing characterisation (type, series, etc.)				2+
Storing parameters (units, racks, handling method)				3
Elements involved (types, quantities, relations)				3
Handling units (sizes, weight, pcs involved)				5
4. Elements	elements	n_e	p_e	**→15+**
Physical parameters (sizes, weight, shape)				5
Handling units (sizes, weight, pcs involved)				5
Storing parameters (units, racks, handling method)				3
Handling parameters (clutching method, orientation, etc.)				2+
B) Influencing parameters			p_I	**→23+**
1. Environment parameters			p_{ep}	**→11+**
Physical limits (location restrictions and prescriptions, etc.)				3+
Environmental effects (temperature, humidity, wind, dust, chemicals, etc.)				5+
Influencing systems (transports, services, relations)				3
2. Changing of the production			p_{cp}	**→12+**
Stochasticity of the processes (orders, supply, scheduling, etc.)				3+

Quantities (series, loading units, transport units, etc.)				3+
Types (variations, minor differences, etc.)				2+
Elements (availability, distribution, etc.)				2+
Raw materials (availability, distribution, etc.)				2+
C) Handling parameters			p_H	**→58+**
1. Handling relations	handling relations	n_{hr}	p_{hr}	**→17+**
Source objects (types, locations)			4	
Destination objects (types, locations)			4	
Handling specifications (clutching, orientation, movement, etc.)			3+	
Handled goods (types, units, sizes, quantities)			6	
2. System objects	system objects	n_{hs}	p_{hs}	**→13+**
Object locations (x, y, z)			3	
Object area (D, W, H)			3	
Handling specifications (clutching method, storing possibility, etc.)			2+	
Handled units (sizes, weights, shape, etc.)			5+	
3. Handling equipment	machines	n_{he}	p_{he}	**→16+**
Machine types (variations, specifications, etc.)			6+	
Physical parameters (sizes, weights, etc.)			4+	
Capacities (loading, transport, speed, etc.)			3+	
Operation parameters (characteristics, driving specifications, etc.)			3+	
4. Handling processes			p_{hp}	**→12+**
Processes (types, times, breaks, etc.)			4+	
Specifications (tasks, time-limits, joining, etc.)			3+	
Equipment (types, applicability limits, additional elements, etc.)			3+	
Process relations (types, joining possibilities, etc.)			2+	
Reference number for the design process:			R_{st}	**Σ 149**

Based on (2), (3), (4) and *Table II*, the complexity level of an integrated design process can be calculated easily. As an example, we defined a system with given number of manufacturing objects, products, elements, handling relations, handling objects and machines, and applied a given value for the object coefficients (f_i). Results of the complexity calculation with the predefined data can be followed in *Table III*.

Of course, the applied values influence the complexity level of the system, however if we use the same values for all the design processes, we can compare the complexities of them. If we want to use this concept for a real material handling system, we need to determine the parameters and the numbers of the objects, products, elements, handling relations, handling objects and machines in the system exactly, and we also have to use a predefined value for the object coefficients (f_i).

Table III.
Calculation of the complexity level of an integrated design process

	A) Production parameters				B) Influencing parameters		C) Handling parameters			
	1. Manufacturing system	***2. Production process***	***3. Product***	***4. Elements***	***1. Environment parameters***	***2. Changing of the production***	***1. Handling relations***	***2. System objects***	***3. Handling equipment***	***4. Handling processes***
Number of parameters	p_{mp}	p_{pp}	p_p	p_e	p_{ep}	p_{cp}	p_{hr}	p_{hs}	p_{he}	p_{hp}
	19	16	18	15	11	12	17	13	16	12
Number of elements	n_{mo}	–	n_p	n_e	–	–	n_{hr}	n_{hs}	n_{he}	–
	10	–	5	30	–	–	10	12	5	–
Coefficients	f_{mo}	–	f_p	f_e	–	–	f_{hr}	f_{hs}	f_{he}	–
	0.5	–	0.5	0.5	–	–	0.5	0.5	0.5	–
Total values:	**60**	**16**	**40**	**82**	**11**	**12**	**54**	**45**	**36**	**12**
	Σ 198				**Σ 23**		**Σ 147**			
Complexity level:	**368 / 149 = 2.47**									

To evaluate the complexity level of the full integrated design process, we have to compare it with smaller tasks, however they can be very different. It is out of the scope of our paper to present the complexity of all design tasks, so we will show the details of one task (unit-load planning).

Table IV contains the calculation of the complexity level for unit-load planning, where we can see that fewer parameter groups and parameters have to be taken into consideration. In the aspect of the numbers of the objects, products, elements, handling relations, handling objects and machines in the system, the same values are applied than during the integrated design process. It is also true for the object coefficients (f_i) and the reference number (R_{st}).

As it can be seen in *Table III* and *IV*, in the example system, the complexity level of the single unit-load planning (1.59) is significantly lower than the value of the integrated design (2.47). In this concept, the minimal value of the complexity level theoretically can be $C_{task} = 1$, which means that we use only one system element in every parameter groups. Comparing the complexity levels of the integrated design solution and the unit-load planning, we can evaluate the work related to the processes in the different cases.

An important question is how we can calculate the complexity level of the design process, if we have to use more than one design task in one process together.

Table IV.
Calculation of the complexity level of unit-load planning

	A) Production parameters				B) Influencing parameters		C) Handling parameters			
	1. Manufacturing system	***2. Production process***	***3. Product***	***4. Elements***	***1. Environment parameters***	***2. Changing of the production***	***1. Handling relations***	***2. System objects***	***3. Handling equipment***	***4. Handling processes***
Number of parameters	p_{mp}	p_{pp}	p_p	p_e	p_{ep}	p_{cp}	p_{hr}	p_{hs}	p_{he}	p_{hp}
	–	–	15	15	3	–	17	10	10	7
Number of elements	n_{mo}	–	n_p	n_e	–	–	n_{hr}	n_{hs}	n_{he}	–
	–	–	5	30	–	–	10	12	5	–
Coefficients	f_{mo}	–	f_p	f_e	–	–	f_{hr}	f_{hs}	f_{he}	–
	–	–	0.5	0.5	–	–	0.5	0.5	0.5	–
Total values:	**0**	**0**	**34**	**82**	**3**	**0**	**54**	**35**	**22**	**7**
	Σ 116				**Σ 3**		**Σ 118**			
Complexity level:	**237 / 149 = 1.59**									

5.2. Complexity level of KBE methods in material handling

In case of using more than one design tasks together, we can take the complexity levels of the individual tasks into consideration (e. g. apply the higher complexity level of them), however it does not give suitable result, because the common solution usually requires iterative techniques. The best is if we recalculate the complexity of the tasks taking all the parameters and other influencing factors of every task into account. The resulted complexity level will be higher than in the individual cases *(Table V)*. In special cases, if the parameters used in the tasks are the same, the complexity levels of the tasks and the common solution will be also the same. As an example we described the parameters of unit-load planning and device planning in *Table V*. to show the effect of the common solution.

Application of augmented and full KBE systems needs similar calculations process to determine the complexity level, however the linked KBE solutions gives different results.

In linked KBE systems, the KBE and CAD methods are principally separated during the process, so the complexity level of them has to be calculated in a different way.

In most of the cases, the KBE and CAD methods meet only some special parameters (in our example these are the physical and handling parameters of the unit-load device), which do not increase the complexity of the process. If the linking interface uses more, additional parameters for the planning, these will increase the complexity level of the design procedure. As in our example, the linking interface does not use other parameters, the complexity level of the solution will be the same as the higher value of the two involved design tasks *(Figure 5)*.

Table V.
Effect of the common task to the number of the parameters

PARAMETER TYPES	Parameters taken into account during the design process		
	Unit-load planning	*Device planning*	*Unit-load + device planning*
A) Production parameters	**→ 30**	**→ 0**	**→ 30**
1. Manufacturing system	**0**	**0**	**0**
2. Production process	**0**	**0**	**0**
3. Product	**15**	**0**	**15**
4. Elements	**15**	**0**	**15**
B) Influencing parameters	**→ 3**	**→ 0**	**→ 3**
1. Environment parameters	**3**	**0**	**3**
2. Changing of the production	**0**	**0**	**0**
C) Handling parameters	**→ 44**	**→ 53**	**→ 53**
1. Handling relations	**17**	**17**	**17**
2. System objects	**10**	**13**	**13**
3. Handling equipment	**10**	**16**	**16**
4. Handling processes	**7**	**7**	**7**
Total:	**77**	**53**	**86**

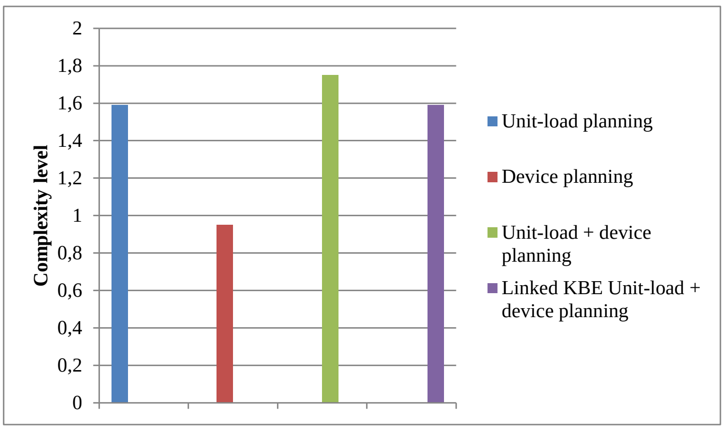


Figure 5. Complexity levels of the analysed cases

One of the most important consequences of our analysis is that the complexity level of a linked KBE solution is in generally lower than the integrated application of two different material handling design tasks. Of course, we need additional work to make an interface program for the linked KBE solution, but it will save time and work for the user during the application process.

Of course, the main objectives of this complexity analysis were to define and explain a method which is suitable to compare the different material handling design methods. In this paper we described this method in generally and apply it for a given example to demonstrate the applicability and analyse the effects to a linked KBE solution.

The general analysis and the description of the details of this concept is out of the scope of this paper, but this will be the next step of our research. We hope that the new concept will be applicable for the evaluation of many practical design methods in the field of material handling (e. g. device selection, facility planning).

6. Summary

Knowledge Based Engineering systems are advanced, effective techniques, which can deliver useful solutions for every field of the industry. There are different variations of KBE systems for the design of material handling machines and processes, one of these methods use the linked KBE/CAD concept which suitable for different handling processes.

Material handling parameters have significant role in the design processes, so in this paper we gave an overview about their most important categories and described a calculation method to determine the complexity level of the material handling systems.

To show the applicability of the complexity level in the design process we presented some examples, which can help to compare the complexity of the different design tasks and processes. As a result, we state that the use of linked KBE/CAD systems can reduce the complexity level significantly which is a great advantage in the aspect of the design process.

Next step of our research can be a more detailed analysis of the design tasks related to the material handling processes, which can help to select new task relations to involve the linked KBE concept.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691942. This research was partially carried out in the framework of the Center of Excellence of Mechatronics and Logistics at the University of Miskolc.

References

[1] Milton, N. (2008). *Knowledge Technologies*, Monza: Polimetrica S.a.s.

[2] Telek, P. (2013). Equipment preselection for integrated design of materials handling systems. *Advanced Logistic Systems –Theory and Practice, 7* (2), 57–66.

[3] Malmborg, C. J., Agee, M. H., Simons, G. R. & Choudhry, J. V. (1987). A prototype expert system for industrial truck type selection. *Ind. Eng., 19* (3), 58–64.

[4] Welgama, P. S. & Gibson, P. R. (1995). A Hybrid Knowledge Based/Optimisation System for automated Selection of Materials Handling System. *Computers Ind. Eng., 28* (2), 205–217.

[5] Cooper, D., Van Tooren, M. & Mohamed, W. M. W. (2008). Keys to Success with Knowledge-based Techniques. In *Proceedings of the Wichita Aviation Technology Congress & Exhibition*, SAE 2008-01-2262, 1–14.

[6] Fan, I. S. & Bermell-Garcia P. (2008). International Standard Development for Knowledge Based Engineering Services for Product Lifecycle Management. *Concurrent Engineering*, *16* (4), 271–277.

[7] Landschuetzer, C., Jodin, D. & Wolfschluckner A. (2011). Knowledge Based Engineering – an approach via automated design of storage/retrieval systems. *Proceedings in Manufacturing Systems, 6* (1), 3–10.

[8] Canals, N. S. (2006). *KBE – Knowledge Based Engineering*, Rapid Product Development RPD, Aida, S.L.

[9] Brimble, R. & Sellini, F. (2000). The MOKA Modeling Language: Knowledge Engineering and Knowledge Management Methods, Models, and Tools. *Lecture Notes in Computer Science*, *1937*, 49–56.

[10] Cooper, D. & Larocca G. (2011). *Knowledge-based Techniques for Developing Engineering Applications in the 21st Century*. Retrieved from www.genworks.com/downloads/kbe2007.pdf.

[11] Ortner-Pichler, A. & Landschützer, C. (2017). Improving geometry manipulation capabilities of Knowledge-based Engineering applications by the versatile integration of 3D-CAD systems. In CD proceedings of the MultiScience – XXVIII. microCAD International Multidisciplinary Scientific Conference (C1: Logistics section, 3.), University of Miskolc.

[12] Landschützer C. & Jodin D. (2012). *Knowledge-based methods for efficient material handling development. Progress in Material Handling Research*, International Material Handling Research Colloquium. Gardanne, France.

[13] Apple, J. M. (1977). *Material handling system design*. New York: John Wiley & Sons.

[14] Ten Hompel, M., Schmidt, T. & Nagel, L. (eds.). (2007). *Materialflusssysteme. Förder- und Lagertechnik.* Berlin: Springer.

[15] Cselényi, J. & Illés, B. (eds.). (2006). *Design and control of material flow systems I. (in Hungarian).* Miskolc: University Press.

[16] Telek, P. (2013). Application of device-preselection for discontinuous unit handling. *Advanced Logistic Systems –Theory and Practice, 8* (1), 93–102.

[17] Bányai, T. (2012). Structured modelling of integrated material flow systems (in Hungarian). *GÉP 63* (4), 83–86.

[18] Jiang, S. & Nee, A. Y. C. (2013). A novel facility layout planning and optimization methodology. *CIRP Annals - Manufacturing Technology 62*, 483–486.

[19] Cselényi, J. & Illés, B. (eds.). (2004). *Logistic systems (in Hungarian).* Miskolc: University Press.

[20] Kota, L. (2012). Optimization of the supplier selection problem using discrete Firefly algorithm. *Advanced Logistic Systems - Theory and Practice 6* (1), 95–102.

[21] Lu, S. C. Y. & Suh, N. P. (2009). Complexity in design of technical systems. *CIRP Annals - Manufacturing Technology 58*, 157–160.