16th Proceedings (Dresden, Germany- 2023)

Progress in Material Handling Research

Summer 6-21-2023

Concepts for the use of knowledge-based engineering in intralogistics system planning

Christian Landschützer
Technische Universitat Graz, landschuetzer@tugraz.at

Alexander Ortner-Pichler
Graz University of Technology, alexander.ortner-pichler@tugraz.at

Recommended Citation

Landschützer, Christian and Ortner-Pichler, Alexander, "Concepts for the use of knowledge-based engineering in intralogistics system planning" (2023). *16th Proceedings (Dresden, Germany- 2023)*. 15.
https://digitalcommons.georgiasouthern.edu/pmhr_2023/15

Concepts for the use of knowledge-based engineering in intralogistics system planning

Alexander Ortner-Pichler
Institute of Logistics Engineering
Graz University of Technology
Graz, Austria
Alexander.Ortner-Pichler@TUGraz.at

Christian Landschützer
Institute of Logistics Engineering
Graz University of Technology
Graz, Austria
Landschuetzer@TUGraz.at

Complex interdependencies of conditions and specifications to be met characterize the planning process of intralogistics systems. In the planning process, a large source of existing knowledge in the form of various 3D CAD machine designs or information from PDM systems is only sparsely used. A newly developed knowledge-based engineering methodology to be presented shows concepts for formalizing, enriching and using this existing knowledge in order to support the planning of intralogistics plants and thus increase their efficiency. The work presented is rounded off by a methodological process that evaluates the usefulness of using a KBE solution.

intralogistics, knowledge-based engineering, system planning, methodology development

I. INTRODUCTION

Even if logistics and intralogistics systems rarely come to the fore, they are essential for all industries. Not only since the advent of globalization inadequate or faulty logistics systems have therefore led to negative effects in almost all areas of daily life. However, various global events in recent years have clearly demonstrated to society the susceptibility to disruption of supply chains that have developed and grown over decades.

Despite all this, rising sales, shipment numbers and investments in logistics real estate are the indicators of a growing logistics industry. Driven by the boom in e-commerce in recent years, intralogistics in particular is proving to be a beneficiary of this development. But this growth goes hand in hand with increasing competitive pressure and the resulting need to make existing processes more efficient. The susceptibility of supply chains to disruptions, in turn, implies the need to implement them in a robust, flexible and secure manner. The first step in implementing these improvements always begins with the correct planning of these systems, thereby laying the foundation for the smooth functioning of the entire process chains.

With the main objective of increasing the efficiency and reducing the error-proneness of the planning process of intralogistic systems, this research work is mainly dedicated to one of the integral components of these systems - the continuous conveyors. Due to their characteristics and the immanent degree of automation, these are suitable for exploring ways to improve the existing planning processes.

On the system level, the existing planning processes are characterized by complex interdependencies with regard to e.g. material flow, cost or process optimization (e.g. [1] highlights that the complexity of intralogistics systems is also influenced by manufacturing companies, which reflect the increasing diversity of product variants. [2] identifies the planning and design based on specific customer requirements as one of the primary factors that contribute to the complexity of intralogistics systems). With regard to the machine level, however, a relatively simple design process can be observed, which is accompanied by product life cycles of many years. Although the machine level trades are developed and designed in three-dimensional CAD packages, the potential of the knowledge available in the designs is left unused in system planning, since system planning mostly still works with reduced geometries in two-dimensional form (for details see e.g. [3] or [4]). Additional to these characteristics the planning process presents itself to be subjective. For example, [5] and [6] attest to the planning process in its practical implementation that planning methods are modified by the experience of the planner, which in some cases leads to system planning based only on the experience of the planner.

These identified characteristics of the planning processes suggest the use of knowledge-based engineering (KBE) methods to more effectively use IT-based tools and link them to existing knowledge.

This publication is embedded in the research topic "Logistics Technology" of the Institute of Logistics Engineering at Graz University of Technology. Ongoing research within this topic focuses on the utilization of existing KBE approaches and the development of new KBE approaches. In 2012 Dirk Jodin and Christian Landschützer proposed (based on shortcomings identified by [7]) in [8] the KBx approach at the 12th IMHRC, differentiating KBE between the various degrees of automation in design work.

In this differentiation the authors describe different design levels by its scopes of use, functions, application (use for) as well as the powering knowledge as: [8]

- Knowledge-based Engineering to be used in KBE applications handling components, parts or machines
- Knowledge-based System Design (KBSD) to be used in applications handling machines or systems
- Knowledge-based System Layouting (KBL) to be used in applications handling systems

The approach was further developed by Landschützer in [9] and gave an initial impulse to the research project to be introduced. The research focuses on the utilization of Knowledge-based Layouting within the boundary conditions of intralogistics system planning and describes therefore the development of a new methodology (see [10] for details). The methodology focuses on following four boundary conditions.

1) Reuse of existing information & use of 3D planning

Existing information crucial for planning, such as 3D machine designs and performance data, is often overlooked or underutilized due to being distributed across different departments and proprietary software solutions. Additionally, the shift towards system integrators has led to the use of static 3D models that cannot be optimized due to file formats not supporting parameterization or associativity. To address this, a boundary condition is formulated to enable the use of existing 3D machine designs, regardless of format and processing methods, using the library-based planning approach.

2) Methodical support of the planning process

With this boundary condition, the influence of the subjectivity identified by e.g. [5], [11] of the planning process is considered. To reduce possible negative, subjective influences in the planning process, a methodical, process-oriented procedure should be made possible.

3) Reduction of complexity

Since the complexity of the considered intralogistics systems can only be reduced to a limited extent, an approach for reducing the complexity of the system modeling is to be developed here. The main approach is the KBx definition according to [8] and [12] and the resulting adaptation of the information depth, depending on the respective application. The KBL domain is suitable for the planning of intralogistics systems.

4) Web-based system & real-time collaboration

The requirement for a web-based system that is capable of real-time collaboration is a constraint that is due more to the multidisciplinarity of the planning process and the zeitgeist of technical development than to the methodological analysis of the planning process.

II. STATE-OF-THE-ART

A good overview of knowledge-based engineering methodologies and applications can be found in [7], [8], [13] and [14]. Each of these literatures differentiates between general purpose KBE methodologies (or full-KBE methodologies according to [8]) and specialized KBE methodologies. In the case of this paper, the specialized KBE methodologies are further distinguished by the reference regarding the integration of CAD systems and the relevance regarding the use in intralogistics.

A. General-purpose KBE methodologies

General-purpose KBE methods enable the creation of almost any KBE application. The most widespread methods to be mentioned here are:

- MOKA: Methodology and Tools Oriented to Knowledge-based Engineering Applications (see e.g. [15], [16])
- KOMPRESSA: Knowledge-Oriented Methodology for the Planning and Rapid Engineering of Small-Scale Applications (see e.g. [17])
- DEE: Design and Engineering Engine (see e.g. [18])
- KNOMAD: Knowledge Nurture for Optimal Multidisciplinary Analysis and Design (see e.g. [19])

All methods share the characteristic of having well-founded processes for knowledge acquisition and processing. As they also have in common that none of these methods provides for the possibility to integrate or process existing knowledge in the form of already created 3D designs or models, which makes library-based planning based on existing 3D designs impossible, they will not be discussed further at this point.

B. Specialized KBE methodologies

In this context, specialized KBE solutions are research and development approaches in the area of knowledge-based engineering that were developed without the use of one of the general-purpose KBE methodologies presented. The research found can be clustered into two categories: Research showing a strong reference to intralogistics and research showing strong reference to CAD.

Two approaches could be identified considering accepts of intralogistics system planning while integrating 3D-CAD geometry into the planning process. [20] shows an approach that demonstrates a strong influence of product configuration. However, this has the consequence that the resulting network information cannot be used, which means that potentials remain unused. [21] shows a proprietary solution of the company Interroll. Since no details have been published in a scientific publication, the exact functionality can only be estimated. As the implementation is done as a plugin in Demo3D, it can be assumed that aspects of CAD are only less pronounced.

Apart from the works documented in [20] and [21] all research found focus on the aspects of intralogistics, without considering the machinery's geometry at all or reducing it to a bounding volume providing only little information, thus disabling a library-based approach as stated in the boundary conditions. As an example, [22] shows a method for planning of distribution centers based on graph theory. [23], [24] show research work based on fuzzy logic systems for conveyor selection. [25] shows the development of a simulation-based planning environment for rough planning of picking systems. Based on a modularized building block system, [26] shows a work on the dimensioning of material flow systems. The tool developed in the research work offers rudimentary possibilities for 3D visualization. [27] shows the development of a system for warehouse planning based on an empirical, matrix-based approach. [28] develop a system for planning picking systems by combining analytical computational methods and semi-automated library-based model generation for sequence simulation. [29] show the development of a progressive simulation method for dimensioning and planning material flow systems.

The works of [7], [13] and [14] offer a good introduction to the research on KBE solutions and approaches with a strong CAD reference. The found research can be clustered by the method used.

1) The Parametric Modeling Method (PMM)

PMM is a frequently used approach in the development of KBE solutions. The basis of the PMM is the separation of geometry generation and manipulation as well as geometry calculation. For geometry generation and manipulation, CAD packages are used that manipulate existing CAD models via appropriate interfaces.

- [30] developed a general-purpose approach for connecting SolidWorks and Microsoft Access by using a Microsoft Visual Basic interface.
- [31] and [32] show approaches to combine a constrained-based approach with the Parametric Modeling Method in their work. These works can partly be assigned to augmented CAD-KBE.

2) *Function Based Modeling (FBM)*

FBM tries to fulfill the given functions of a product or system with the help of artificial intelligence. The method can be realized with the help of different approaches.

- [33] shows a rule-based approach to development for the design of various mechanical systems and mechanisms.
- [34] shows a general-purpose object-based approach.

3) *Assembly based Design (AbD)*

AbD represents a method that attempts to assemble existing components and assemblies into complete systems. It basically represents a KBE variation of the product configuration.

- [35] uses a developed method for knowledge-based component selection and assembly configuration.
- [36] developed a method that is analogous: Assembly oriented design. This method supports the design process in that assemblies can be planned and analyzed without specific knowledge of the component geometries.

III. SYSTEM MARK UP USING THE DEVELOPED METHODOLOGY

Since existing research cannot fully satisfy the identified constraints, a new KBE method was developed to achieve these goals. The developed methodology is based on the following four core concepts, which are roughly described in the following sections (see [10] for further details).

A. *Blackbox encapsulation in an object-oriented structuring*

The Blackbox markup simplifies system modeling by encapsulating all necessary information within a self-contained unit. For instance, a conveyor's dimensions and achievable and calculated throughput are described within a Blackbox. The abstract geometry of the conveyor is represented by its bounding volume and expanded as needed for operation or maintenance. Detailed 3D modeling is performed by a CAD package based on the Blackbox parameters, allowing for quick comparison of different system layouts. The Blackboxes also contain a logic core that can manipulate parameters, such as transforming interfaces when conveyor dimensions are altered.

In order to enable an efficient comparison of variants of different systems, the method employs an object-oriented structuring of the logistics machinery used. The root classes of this multiple inheritance structuring are described mainly by two characteristics: the number of entry and exit points of the material flow, as well as the type of the position change (1D, 2D or 3D) that is imposed on the material flow. This structuring has the advantage that e.g. a straight section of a belt conveyor and a roller conveyor are represented by the same class, if one selects a correspondingly high abstraction level in the structuring.

B. *Interfaces*

To allow the Blackboxes to interact with their environment or other Blackboxes, a means of interaction based on interfaces has been provided. Roughly speaking, an interface is just a tool for matching two parameters across the system boundaries of the Blackbox. However, this alignment does not necessarily have to correspond to an equating of the parameter values, since the parameter values can be changed during the alignment by a transition function. As an example, a standard interface fulfills the tasks of geometric position and orientation alignment and, in parallel, the forwarding of material flow information.

C. *Grouping*

Grouping represents a general concept of the method. It means that each Blackbox can integrate another Blackbox into its own system boundaries. It means that an object of class KBE-element may group child elements and, on the other hand, it also means that each Blackbox, except for the SystemEnvironment Blackbox, has a parent Blackbox. The Blackboxes grouped by a Blackbox (child Blackboxes) may be created, modified and deleted by the logic core of the grouping Blackbox (parent Blackbox).

D. *Logic core*

The logic core represents the central computational logic of the Blackbox and interface elements. Changes to these elements may only be performed by the logic core to correctly handle effects on the environment (or connected Blackboxes). Thus, in geometric terms, the logic core is responsible for computing the transformations of the coordinate systems mapped by geometric interfaces and setting them in correct relation to the local coordinate system of the logic core of a Blackbox. Fig. 1 shows an abstract illustration of a Blackbox containing two interfaces (i1 and i2) as well as the corresponding logic cores.

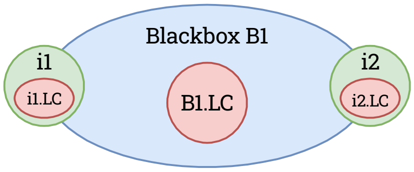


Fig. 1 Abstract representation of a black box and its logic core [10]

Furthermore, this also means that, for example, parameters may not be changed directly, but a change is triggered via the corresponding update function in the logic core. If the change of a parameter is requested, the logic core is responsible for updating all components dependent on this parameter after the parameter has been changed. If interfaces are affected by the change, the logic core triggers the corresponding update functions of the connected Blackbox.

The figure shows an abstract representation of a Blackbox that has two interfaces and their logic core (one logic core for each interface and one logic core of the Blackbox). This abstract system can be described in general terms by various properties e.g., “a logic core may or may not be determinate” (In the context of the method, the term "determined" describes the state of information (e.g. the value of a parameter) that is not stored as a default value but has been specified by a user of the method. Information that is directly dependent on determined information is also considered determined in this context.) or “a logic core may influence other logic cores”. The logic core’s logic was developed by describing the system Blackbox and its properties by an elementary propositional logic (e.g., "A logic core has a value.", "A logic core can be determined."). If one now varies these properties, one can mentally analyze the effects on the system and describe them by means of compound statements of propositional logic. These composite statements (Fig. 2 shows a first version of the developed logic structuring the composite statements in sequence) form the core of the actualization function. The final version can be found in [10].

```
BEGIN OPERATION UpdateFunction()

Z2:  Check the references of the own determination.
     Delete the own determination if a reference is undefined

Z3:  Check the possibility of a determinate calculation

Z1:  If a determinate calculation is possible:
     Perform a determinate calculation.

  Z6: Check a possible determination of influenced logic kernels.

¬Z1 ∧ Z4: If no determinate calculation is possible,
          an undefined calculation is performed:
          Perform an undefined calculation.

  Z6:     Check if the loss of determination affects
          other logic kernels.

END OPERATION
```

Fig. 2 Composite statements forming the core of the update function

To be able to describe a material flow system, the method provides for the management of the corresponding information in different logic cores. This means that a material flow system that is described, for example, in terms of geometry and throughput, also requires two logic cores in each Blackbox and each interface to manage the corresponding information.

E. Exemplary specification of logistics machinery

In the following section, the material flow elements source, sink and a straight roller conveyor are shown. The modeling of these elements in the context of the method are deliberately kept simple and reduced to the most necessary for the description of the calculation processes (i.e. rudimentary geometry and throughput).

The basic structure is identical for all elements shown and consists of two information layers, each of which is represented by separate logic cores. One layer represents the geometric information and one the information of the material flow. UML class and object diagrams containing the complete formalization of the methodology are shown in [10].

1) System-environment blackbox

As a special form of black box, the system-environment Blackbox should be noted at this point at first. This Blackbox represents the system environment of all other Blackboxes. In principle, it is comparable to the ground body from various multi-body simulation models. The system environment Blackbox differs from all other Blackboxes in that it has no geometric expression and, as the only element of a complete system, has no parent element and thus cannot be grouped. As a result, a system environment black box can exist exclusively only once in each overall system.

2) Source & sink

The material flow elements source and sink show a straightforward structure, which is characterized regarding geometry by parameters indicating width, length and height. In order to position these Blackboxes, both show an interface in the middle of the base for an interconnection with the environment and one interface on the top. In terms of material flow, they are similarly simply mapped: the source has a parameter that describes the throughput emitted into the system. The sink, as an analogue, has a parameter describing the throughput leaving the system via the sink.

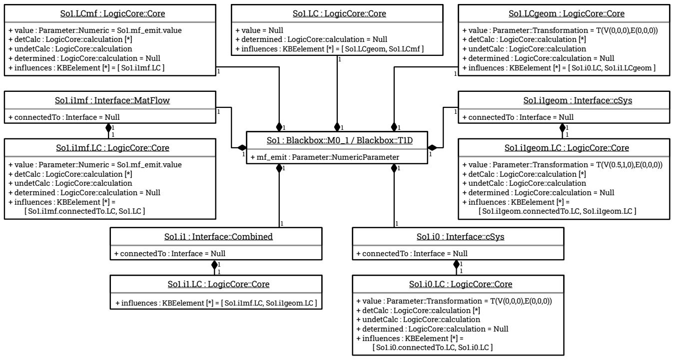


Fig. 3 Sections of a UML object diagram of a source element [10]

Fig 3. shows an UML object diagram of a source element marked up by the developed methodology. The diagram only shows a section of the components that would be required for a complete implementation. The diagram shows the information layers for processing the material flow information (postfix mf) and the geometry information (postfix geom). As an example, the logic core So1.LCgeom (the notation is based on the notation of the JavaScript programming language and means that LCgeom is a component of the So1 object) is responsible for managing the geometry information and influences the two geometric interfaces based on its own value (So1.LCgeom.value), which in this case is represented by a transformation matrix.

3) Straight Conveyor

Identical to the source and sink Blackbox, the straight conveyor is implemented regarding its geometry by the parameters width, height and length. As shown in Fig. 4 the straight conveyor features two interfaces (shown as Cartesian coordinate system) enabled to transfer the information regarding geometry and throughput from one Blackbox to another.

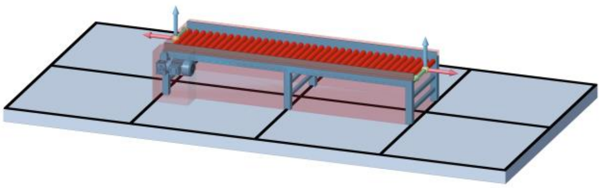


Fig. 4 Straight conveyor marked up as Blackbox [10]

IV. DISCUSSION OF THE CALCULATION LOGIC

Fig. 5 shows an exemplary initial state of a material flow system containing four Blackboxes (source So1, straight conveyor C1 and a sink Si1 as well as a grouping Blackbox CG1, that contains C1 and allows its exchange) implemented as stated in the previous section.

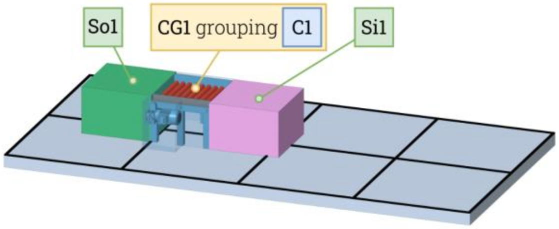


Fig. 5 System calculation (first example): initial state [10]

The source So1 is interconnected to the system-environment Blackbox using the Blackbox’s interface in the ground and the parameter specifying the emitted throughput is set to zero. When interconnecting the grouping Blackbox to the source and sink Blackboxes, the system is calculated to the initial state as shown in Fig. 5. In this state, the grouping Blackbox CG1 chooses the most appropriate variant available, which is the shortest variant (as the sink Si1 has no fixed position) featuring the lowest conveyor speed (as the emitted throughput of the source So1 is set to zero). By interconnecting the Sink to the grouping Blackbox, its position is calculated undetermined (i.e. it is not calculated determined by a set of standard parameters) by the position of the source and the length of the grouping Blackbox.

When changing the source’s emitted throughput to a positive value different from zero, the system reacts with the following procedure:

- The throughput’s parameter value is held by the source’s logic core and as it is updated and thus determined, the according value is set within the logic core of the interface.
- This value is “mirrored” to the grouping Blackbox’s first interface. That means that the absolute value of both parameters is set equal and the Blackbox’s parameter value is modified by a transition function in the form of a multiplication by minus one (The method implements a sign convention, in which material flow entering a Blackbox is considered to be positive and leaving a Blackbox is considered to be negative).
- As the grouping Blackbox is now aware of the changed throughput, it automatically chooses a conveyor variant (C1) featuring an appropriate conveyor speed.

Furthermore, in this scenario, the system can react to a changed position of the sink as well. When interconnecting the Sink to system-environment Blackbox, its position can be calculated determined. That means that calculation logic is now aware of the user wanting it to bridge the distance between the source and the sink as both are set by the user.

In this scenario, the system reacts as following:

- As the position of the source and the sink can now be calculated determined in relation to the system-environment Blackbox, the interfaces of the grouping Blackbox are both determined as well.
- In order to fulfill this constraint, the grouping Blackbox chooses another variant (C2), that bridges the distance between the source and the sink and features a conveyor speed high enough, to deliver a sufficiently high throughput.
- The system presents itself as shown in Fig. 6.

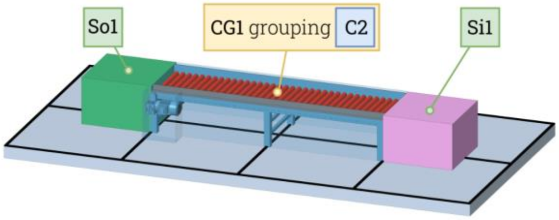


Fig. 6 System calculation (first example): final state [10]

As a second example, Fig. 7 shows another system whose system calculation using the developed methodology is to be roughly described. The system is built up from a closed circuit consisting of two straight conveyors (C1 and C2) and two grouped conveyor sections (CG1 and CG2) for mapping the curves. At both ends of the straight conveyors, two sources (So1 and So2) and two sinks (Si1 and Si2), respectively, are incorporated by means of merging and split elements for the infeed and outfeed of goods.

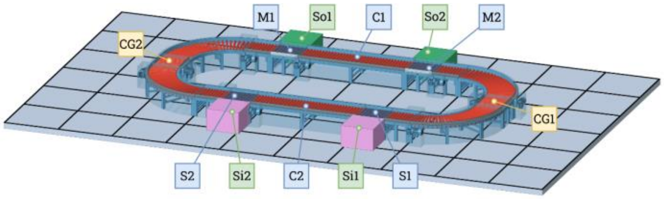


Fig. 7 System calculation (second example): closed loop system [10]

Probably the most interesting behavior of the system calculation is shown in a thought experiment in which only the source So1 is connected to the system (i.e. the second source and both sinks are not connected to the loop). If one looks at the state that arises directly after the connection of the source So1 with the element for merging (M1) in the system, it can observed that the throughput of the Blackbox M1 can only be partially calculated determined. The material flow emitted into the system starting from the source So1 defines the incoming material flow at only one interface of the merge element. The second interface (material flow from CG2) is calculated undetermined with a throughput of zero. The material flow is now calculated throughout the system at the value of the emitted throughput of source So1 until the information arrives back at the merge M1. In the next iteration step, the throughput is calculated at twice the emitted throughput and in the following one at three times the emitted throughput. This process is repeated in an endless loop, whereby in each calculation of the loop the value of the emitted throughput is added to the current material flow. The behavior can be subsumed exaggerated to the following statement: When connecting a closed system with only one source, the closed system gradually runs full. Since this behavior also corresponds in a certain way to the behavior of a real system, it is not interpreted as a misbehavior.

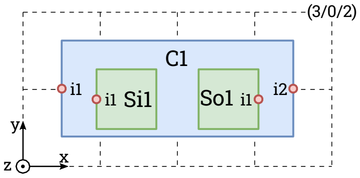


Fig. 8 Compensation element [10]

Even though this problem will rarely occur in the practical implementation of the planning process, this possible infinite loop can be circumvented by a compensation element. By designing the Blackbox shown in Fig. 8, the infinite loop stops at the sink. In addition to preventing the infinite loop, the compensation element can also be used to implement a base load to represent returns on a conveying circuit. For this purpose, a corresponding material flow can be emitted by the source.

The authors refrain from a further detailing of the processes of the system calculation at this point and refer to [10], in which further examples are shown, since the necessary space requirement would exceed the scope of this publication due to the complexity caused by the description of the various recursive calls of the individual update functions.

V. EVALUATION PROCESS FOR THE USE OF KBX

The Blackboxes may appear relatively simple at first glance, but the UML diagram in Fig. 3 shows in broad strokes that the effort required to map a single logistics machine should not be underestimated. Implementing a company's whole product range - especially the structuring in an adequate derivation tree - is a time-consuming process.

When evaluating one of the research's main objectives of increasing the efficiency of the planning process of intralogistics systems, one must distinguish therefore between the operative and overall efficiency. The operative efficiency is a priori increased by a more effective use of IT-tools as stated within the methodology. Evaluating the overall efficiency is more complex, as this depends strongly on the implemented product range and the frequency of use and thus can only be evaluated in every special case of application.

If one continues this thought consequently, one ends up with the question whether knowledge-based engineering is useful for the given purpose or application. A systematic approach consisting five steps was developed in [9] and [37] to help answer this question. As the stated process to be introduced in the following is not only limited to intralogistics system planning specifics of the system planning are added as well without referring to the KBE/KBSD/KBL methodology in particular.

1) Construction / design type

Even though the type of construction is implicitly recorded in the question table of the following process step (2), it must be checked at the beginning in which boundary conditions the KBE solution is to be created. This cannot be measured quantitatively and, like all KBE creations, must be adapted to the situation.

In principle, a KBE solution is usually only suitable for variant design or adaptation designs (see [38] for details). In contrast to that, KBE solutions are only suitable to a limited extent for new designs. When evaluating the deployment of a KBE solution assisting the layout planning, the evaluation process must not consider the overall system, but the machinery or subsystems (especially the length and state of a product's life cycle) used within the layouting process.

2) evaluation of the KBE application

Within a guided testing process questions in the categories "necessity", "entrepreneurial benefit", "efficiency", "Work technique", "knowledge retention" and "interdisciplinary collaboration" are presented to the evaluator. It tries to clarify if implementing a KBE solution can be considered useful or not. Even if this guided testing process tries to answer this question in a methodical and objective way, it can only help to identify tendencies, as the rating of the weighting and the criteria is subjective by nature. To reduce the subjective aspects of the rating, this evaluation process should be carried out by several evaluators.

Each of the questions asked need to be weighted in a first step using e.g. a pairwise comparison or any other method of choice, as the testing process calculates a utility value for each of the categories, by calculating the quotient of the actual rating and the maximum achievable rating. When the evaluation scores a value lower than 50% in a single category it must be questioned, if implementing the KBE solution is useful.

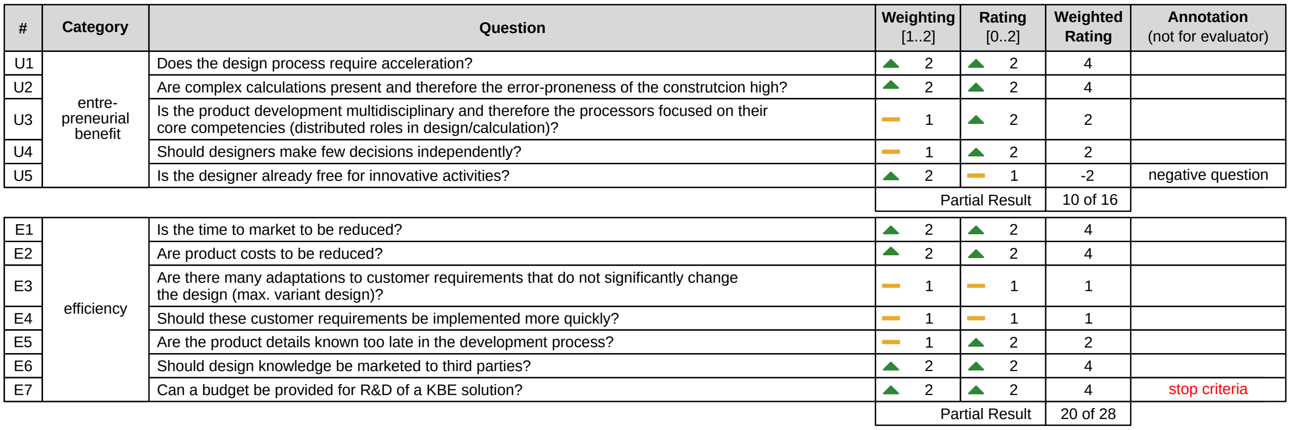
Fig. 9 shows an excerpt of the question table of the categories "entrepreneurial benefit", "efficiency" (a more exhaustive list can be found in [9]). Next to some regular questions (i.e. the rating between zero and two is weighted and summed up to the utility value), the last questions of both categories shown, are considered to be special questions. The last question of the first category can be seen as a check question, reducing the category's utility value. Even if the last question of the second category is calculated similarly to a regular question, it has to be evaluated especially in the next step (3) as it is specified as a stop criteria.

3) Stop criteria

As mentioned in the previous step, the question table features three questions defined as stop criteria. When rating one of these questions in the negative (i.e. a rating under the maximum score of two), it is likely that the KBE solution will not be implemented successfully.

- Can a budget be provided for R&D of a KBE solution?
- Is the budget and capacity still available to support the KBE solution after it has been created?
- Are employees willing to disclose knowledge?

The first two stop criteria questions may be answered with more ease than the last one, as both rating the economical situation of the KBE solution's implementation. The last question can be considered as the most crucial, as it tries to answer the mere possibility of implementing the KBE solution. Only if a company's employees are willing to help to formalize their implicit knowledge into explicit knowledge, a KBE



#	Category	Question	Weighting [1..2]	Rating [0..2]	Weighted Rating	Annotation (not for evaluator)
U1	entre-preneurial benefit	Does the design process require acceleration?	▲ 2	▲ 2	4	
U2		Are complex calculations present and therefore the error-proneness of the construtcion high?	▲ 2	▲ 2	4	
U3		Is the product development multidisciplinary and therefore the processors focused on their core competencies (distributed roles in design/calculation)?	▬ 1	▲ 2	2	
U4		Should designers make few decisions independently?	▬ 1	▲ 2	2	
U5		Is the designer already free for innovative activities?	▲ 2	▬ 1	-2	negative question
			Partial Result		10 of 16	
E1	efficiency	Is the time to market to be reduced?	▲ 2	▲ 2	4	
E2		Are product costs to be reduced?	▲ 2	▲ 2	4	
E3		Are there many adaptations to customer requirements that do not significantly change the design (max. variant design)?	▬ 1	▬ 1	1	
E4		Should these customer requirements be implemented more quickly?	▬ 1	▬ 1	1	
E5		Are the product details known too late in the development process?	▬ 1	▲ 2	2	
E6		Should design knowledge be marketed to third parties?	▲ 2	▲ 2	4	
E7		Can a budget be provided for R&D of a KBE solution?	▲ 2	▲ 2	4	stop criteria
			Partial Result		20 of 28	

Fig. 9 Excerpt of the question table [9]

solution can be implemented successfully (see [39] for a differentiation of implicit and explicit knowledge).

4) Differentiation of the scope and objectives

The differentiation in KBx limits the intended use and scope as well as the overall degree of design automatization of the KBx solution and specifies the main functions to be implemented. The specified rule classes with the necessary data and information span a framework of the knowledge to be used.

5) Implementation of the KBE soluation

As according to [7], the process of creating a KBE is always adapted to the situation, the authors refrain from further detailing this process step.

VI. SUMMARY AND OUTLOOK

This paper describes a concept for a new knowledge-based engineering methodology that attempts to utilize existing information in a more efficient way. The methodology developed focuses on constraints in the design of intralogistics systems, but is applicable to a wide range of applications, particularly systems based on networks.

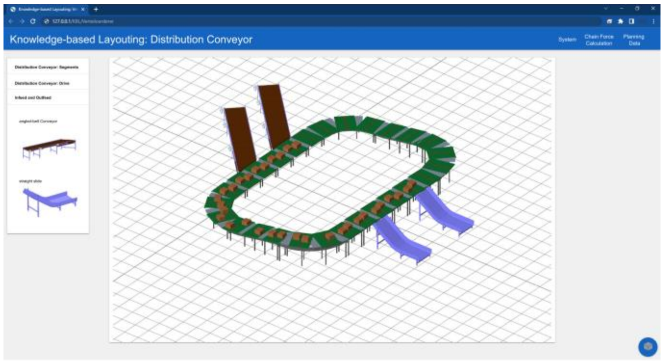


Fig. 10 Exemplary prototypical implementation (distribution conveyor)

In particular, the methodology extends related research by integrating the parametric modelling method and thus the full usability of existing 3D CAD geometry as well as providing the ability to generically design an intralogistics system using a library-based planning approach, allowing system variants with different technical characteristics to be easily compared. This procedure should help to bring ideal and rough planning closer together. In addition, the methodology reduces system complexity by encapsulating subsystems while retaining the ability to use generated material flow network information within machine specification and configuration to generate encapsulated optimization cycles.

The demand for possibilities to increase the efficiency of the planning process - also on the part of the industry - is not only implicitly shown by the presentation of increasing shipment numbers and real estate investments, but also explicitly, exemplified by the Interroll Layouter. In many discussions with system providers in the intralogistics sector, it also became clear that many tools with a similar focus are available for internal use in the respective companies.

Besides the verification (see [10]) of the system planning results using the method, the method has also been tested in various prototypical implementations and has proven its functionality. Fig. 10 shows one of these prototypical implementations in a web-based environment that allows the planning of a distribution conveyor. The implementation allows a user to assemble a distribution conveyor from straight pieces, curves, and inclining elements. All elements can be configured in detail through an asynchronous machine configuration.

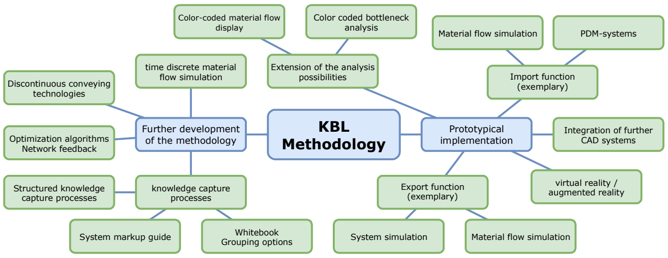


Fig. 11 Future and ongoing research realated to the methodology

Since the current research is intended to be foundational work in the topic, a broad spectrum of follow-up research can be identified. Fig. 11 shows examples of various topics that are being worked on at the Institute of Logistics Engineering ranging from the further development of the methodology to the expansion of the range of prototypical implementations. The current main focus is on the specification of structured processes for knowledge acquisition and knowledge formalization.

REFERENCES

[1] M. Winkler, „Grenzen des Wachstums für Distributionszentren" in Intralogistik 4.0?! Logistikwerkstatt Graz 2015 (Editor: Jodin, D.), Verlag der Technischen Universität Graz, Graz, 2015, pp. 193-199.

[2] R. Yousefifar, T. Beyer, N. Jazdi, K.-H. Wehking, P. Göhner, „Dezentrale selbstorganisierte Grobplanung von Intralogistiksystemen mit Hilfe eines Software-Agentensystems" in Logistics Journal: Proceedings 2014, 2014.

[3] M. Eigner, R. Stelzer, „Product Lifecycle Management - Ein Leitfaden für Product Development und Life Cycle Management", 2nd edition, Springer, Berlin, 2009.

[4] J. Rix, S. Haas, J. Teixeira, "Virtual Prototyping. Virtual environments and the product design process" Springer, Berlin, 2016.

[5] B. Jobi, K.-H. Wehking, „Rechnergestützte Planung von Distributionszentren durch Einsatz der Graphentheorie" in Logistics Journal, vol. 2013, iss. 10, 2013.

[6] K.-H. Wehking, „PInLog - Entwicklung einer Planungsplattform für intralogistische Systeme." Abschlussbericht des Instituts für Fördertechnik und Logistik der Universität Stuttgart zu dem durch das Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg in Kooperation mit dem Intralogistik Netzwerk in Baden-Württemberg e.V. geförderten Vorhaben 32-729.85/151, Stuttgart, 2010.

[7] W.J.C. Verhagen, P. Bermell-Garcia, R.E.C. van Dijk, R. Curran, "A critical review of Knowledge-Based Engineering: An identification of research challenges" in: Advanced Engineering Informatics, vol. 26, iss. 1, Elsevier, 2012, pp. 5-15.

[8] D. Jodin, C. Landschützer, Knowledge-based methods for efficient material handling equipment development, 12th IMHRC Proceedings (Gardanne, France – 2012), 2012, pp. 231-250.

[9] C. Landschützer, „Methoden und Beispiele für das Engineering in der Technischen Logistik", Habilitationsschrift, Schriftenreihe des Instituts für Technische Logistik, Verlag der Technischen Universität Graz, Graz, 2016.

[10] A. Ortner-Pichler, „Konzepte zur Nutzung von Knowledge-based Engineering in der Planung intralogistischer Stetigförderersysteme", Dissertation, Technische Universität Graz, 2022.

[11] D. Marrenbach, K.-H. Wehking, "Autopoetic material handling systems" in: Proceedings of the 16th Annual International Conference on Industrial Engineering Theory, Applications and Practice, Stuttgart, 2011.

[12] D. Jodin, C. Landschützer, „Wissensgestützte Methoden und Werkzeuge zur Geräteentwicklung und -konstruktion in der Technischen Logistik" in: Jahrbuch der Logistik, 2014, pp. 40-45.

[13] E. Jayakiran Reddy, C.N.V. Sridhar, V. Pandu Rangadu, "Knowledge Based Engineering: Notion, Approaches and Future Trends" in: American Journal of Intelligent Systems, vol.5, Scientific and Academic Publishing, 2015, pp. 1-17.

[14] G. La Rocca, "Knowledge based engineering: Between AI and CAD. Review of a language based technology to support engineering design" in: Advanced Engineering Informatics, vol. 26, Elsevier, Amsterdam, 2012. pp. 159-179.

[15] R. Brimble, F. Sellini, "The MOKA modelling language" in: Knowledge Engineering and Knowledge Management - Proceedings of the 12th International Conference EKAW 2000, Springer, Berlin/Heidelberg, 2000, pp. 49-56.

[16] M. Stokes, "Managing Engineering Knowledge – MOKA: Methodology for Knowledge Based Engineering Applications", Wiley-Blackwell, Hoboken, 2001.

[17] P.J. Lovett, A. Ingram, C.N. Bancroft, "Knowledge-based engineering for SMEs - a methodology" in: Journal of Materials Processing Technology, vol. 107, Elsevier, 2000, pp. 384-389.

[18] C.A. Cooper, "Development of a Methodology to Support Design of Complex Aircraft Wings", Dissertation, Technische Universität Delft, Fakultät Aerospace Engineering, 2011.

[19] R. Curran, W.J.C. Verhagen, M.J.L. van Tooren "The KNOMAD Methodology for Integration of Multi-Disciplinary Engineering Knowledge within Aerospace Production" in: 48th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida, 2010.

[20] M. Ghoffrani, „Entwicklung und Einführung eines flexiblen Softwaresystems zur Konfiguration virtueller Produkte", Dissertation, Ruhr-Universität Bochum, Bochum, 2007.

[21] Interroll (Schweiz) AG: „Interroll präsentiert neue Plug-and-play-Förderplattform für automatisierte Produktionsumgebungen", Online: https://www.pressebox.de/inaktiv/interroll-holding-ag/interroll-praesentiert-neue-plug-and-play-foerderplattform-fuer-automatisierte-produktionsumgebungen/boxid/1111439 (Accessed: 23.05.2022)

[22] B. Jobi, „Entwicklung einer rechnergestützten Systematik zur funktionsbereichsübergreifenden Planung von Distributionszentren durch Einsatz der Graphentheorie", Dissertation, Universität Stuttgart, Stuttgart, 2013.

[23] O. Kulak, "A decision support system for fuzzy multiattribute selection of material handling equipments" in: Expert Systems with Applications, vol. 29, Elsevier, 2005, pp. 310-319.

[24] S. Hamid, L. Mirhosseyni, P. Webb, "A Hybrid Fuzzy Knowledge-Based Expert System and Genetic Algorithm for efficient selection and assignment of Material Handling Equipment", in: Expert Systems with Applications, vol. 36, Elsevier, 2009, pp. 11875-11887.

[25] A.S. Ulbrich, „Simulationsgestützte Grobplanung von Kommissioniersystemen", Dissertation, Technische Universität München, 2010.

[26] I. Meinhardt, H-G. Marquardt, „Offenes Baukastensystem zur effizienten Dimensionierung von Materialflusssystemen" in: Logistics Journal, vol. 2007, 2007.

[27] J.M. Apple Jr., R.D. Meller, J.A. White Jr. "Empericallybased warehouse design: Can academics accept such an approach?", in: 11th IMHRC Proceedings, (Milwaukee, USA – 2010), 2010.

[28] W.A. Günthner, S. Galka, A. Ulbrich, „Neue Werkzeuge für die Planung von Kommissioniersystemen", in: Jahrbuch der Logistik, 2009, pp. 285-289.

[29] S. Hilbrich, H. Köck, J. Hinckeldeyn, J. Kreutzfeldt, „Entwicklung einer Simulationsmethodik zur schnellen Dimensionierung komplexer Materialflusssysteme", in: Logistics Journal : Proceedings 2017, 2017.

[30] D. Yao, Z. Chang, J. Zhao, Y. Dou, "Study on Key Techniques of Parametric Design System Based on Solid Works and KBE", in: Applied Mechanics and Materials, vol. 71-78, 2011, pp. 3861-3867.

[31] Y. Bodein, B. Rose, E. Caillaud, "Explicit reference modeling methodology in parametric CAD system", in: Computers in Industry, vol. 65, Elsevier, 2014, pp. 136-147.

[32] J.D. Camba, M. Contero, P. Company, "Parametric CAD modeling - Analysis of strategies for design reusability", in: Computer-Aided Design, vol. 74, Elsevier, 2016, pp. 18-31.

[33] C.L. Li, S.T. Tan, K.W. Chan, "A qualitative and heuristic approach to the conceptual design of mechanisms", in: Engineering Application of Artificial Intelligence, vol. 9, iss. 1, 1996, pp. 17-32.

[34] S. Akagi, K. Fujita, "Building an Expert System for Engineering Design Based on the Object-Oriented Knowledge Representation Concept", in: Journal of Mechanical Design, vol. 112, ASME, 1990, pp. 215-222

[35] P. Jaiswal, J. Huang, R. Rai, "Assembly-based conceptual 3D modeling with unlabeled components using probabilistic factor graph", in: Computer-Aided Design, vol. 74, Elsevier, 2016, pp. 45-54.

[36] X.F. Zha, H.J. Du, J.H. Qiu, "Knowledge-based approach and system for assembly oriented design - Part I the approach", in: Engineering Applications of Artificial Intelligence, vol. 14, 2001, pp. 61-75.

[37] C. Landschützer, D. Jodin, "Engineering for logistics" in: Proceedings in Manufacturing Systems, vol. 11, iss. 1, 2016. pp. 63-70.

[38] J. Feldhusen (ed.), K.H. Grote (ed.), G. Pahl, W. Beitz, et.al., „Pahl/Beitz Konstruktionslehre: Methoden und Anwendung erfolgreicher Produktentwicklung", 8th edition, Springer-Verlag Berlin Heidelberg, Berlin, 2013.

[39] Verein Deutscher Ingenieure (ed.), „VDI-Richtlinie 5610 - Blatt 1: Wissensmanagement im Ingenieurwesen - Grundlagen, Konzepte, Vorgehen", Beuth-Verlag GmbH, Berlin, 2009.