# Towards intelligent material handling planning systems – Status quo and steps to be taken –

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**Abstract.** The process of planning material handling systems is highly complex. By applying procedure models, methods, and expert knowledge, a material handling system is designed according to market requirements. The result of this design phase is highly dependent on the expertise and valuation of the human planner. In this respect, software-based decision support systems aim to enable reasonable and comprehensible design decisions. This article presents the vision of intelligent planning systems that are able to transform user requirements into efficient and effective material handling systems. In this respect, two steps that have to be taken in developing intelligent planning systems are discussed.

## 1 INTRODUCTION

Optimal material handling systems are elementary to ensure economical, high-quality, and time efficient operations in distribution structures.

The configuration is developed in a design process, in which market and company requirements are transformed into a material handling system. In this respect, decisions are made on the basis of planning data that take effect on the performance of the designed system.

With these decisions made by human planners, personal opinions and restricted knowledge may lead to a sub-optimal solution. Thus, the demand for intelligent software-based decision support systems arises, which may help to reduce planning uncertainties and enable reasonable results.

## 2 MATERIAL HANDLING SYSTEM DESIGN

*Material handling systems design* aims to create an optimal material handling system for a specified purpose. The design is influenced by technical, economic, and organizational restrictions that may be either internally or externally determined.

The design process is carried out in different stages. In each design step, alternative solutions are created and evaluated according to specified criteria. Then, the superior alternative is chosen and considered in consecutive design phases.

Having analysed relevant literature on procedure models for material handling system planning [1, 2, 3], the following planning steps can be extracted:

At first, planning goals are determined and the planning data basis is set up and analysed. The data basis includes performance requirements, assumptions, expected sales, etc.

After that, the material handling processes are designed. In this respect, different process alternatives are generated, evaluated, and reduced to the most convincing alternative. The selected process alternative highly determines the structure of the material flow.

This material flow structure is developed in the layout planning stage. It includes the calculation of required space per area (e.g. stock receipt, order picking zone), the allocation of processes to these areas as well as locating the necessary equipment according to one or more specified target function(s), e.g. minimum transportation costs, minimum space costs or minimum shape irregularities.

The layout is clearly linked to the *material handling equipment selection* (*MHES*) that includes the choice, dimensioning, and evaluation of proper equipment as well as assessing the resulting material handling system. The choice between conveyors and forklifts or between floor storage and high rack warehouses illustrates different design alternatives.

All developed alternatives have to be assessed according to specific criteria. The most promising alternative is finally planned in detail.

This procedure model also includes the bid invitation of the chosen design alternative and its execution before starting the operating phase of the material handling system.

## 3 MATERIAL HANDLING EQUIPMENT SELECTION (MHES)

The selection of material handling equipment requires a comparison between user requirements and equipment capabilities. According to [4] three different approaches in MHES can be defined:

- *Analytical approaches* incorporate quantitative selection procedures, e.g. on basis of integer programming. They require a mathematical model of the selection problem, commonly formulated as one or more target function(s) that has/have to be optimised according to one or more constraint(s). The necessary quantification of qualitative variables is often highly speculative and may therefore lead to pseudo accurate results that can easily be misinterpreted. Realised analytical approaches for MHES are provided by [5, 6, 7].
- *Knowledge-based approaches* rely on expert knowledge on equipment selection. This knowledge is then transformed into decision rules that compare user requirements with equipment capabilities to select proper material handling resources, e.g. "In case the product mass exceeds 15 kg, employees need to use lifting equipment to handle the product." Realised knowledge-based approaches for MHES are provided by [8, 9, 10, 11].
- *Hybrid approaches* combine knowledge-based and analytical approaches in different steps of the decision process. Therefore, they are not addressed in detail in the following. Realised hybrid ap-

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proaches for MHES are provided by [4, 12]. Now, focus is on the applicability of knowledge-based approaches.

The relevance of all three approaches in equipment selection faces limitations due to the high complexity of inbound logistics: Interrelations between product, process parameters, and layout must be taken into account when selecting a material handling equipment, as they all determine the efficiency and reliability of the material handling system.

Following [11], knowledge-based MHES is performed in several decision steps: The selection process starts with sorting out equipment classes by basic criteria, e.g. the required usage flexibility. After that, static properties of equipment classes, like loading capacities, have to be analysed. This step is followed by using decision trees to incorporate expert knowledge to the decision process.

A detailed cost comparison of the remaining alternatives as well as sensitivity analyses may help to assess the remaining alternatives in different business scenarios. Finally, a detailed simulation study of the chosen system in different situations, e.g. including component failures, is proposed.

As material handling equipment has to be assigned to each process, e.g. truck unloading is to be carried out by forklifts, a process based categorization of equipment is necessary. Thus, relevant material handling reference processes have to be defined, e.g. storing, packaging, moving.

The number and scope of these reference processes is clearly linked to the relevant planning task. This means that reference processes for distribution centres may differ from those for production supply systems.

After setting up the reference process basis, specific decision rules have to be developed for each process. These rules represent expert knowledge in comparing user requirements with equipment capabilities.

Combining each reference process with only a limited number of available equipment types may help to reduce the complexity of the rule development process: Instead of setting up rules that reject forklifts as possible packaging equipment, only explicitly compatible packaging equipment types (e.g. stretching machines) are linked to the packaging reference process.

By applying decision rules to material handling selection problems, equipment types can be reduced to a number of requirement compatible alternatives. This means that the application of each decision rule leads to incompatible devices being dismissed from the decision process.

Finally, only compatible devices remain in a virtual alternatives list. Deciding for only one alternative nevertheless may require detailed analytical or simulative investigation of both the remaining devices as well as the analysis of interrelations in the whole material handling system. In case the system being planned includes $n$ processes and each process can be carried out by $m$ alternative compatible devices, the number of alternative system configurations is up to $m^n$, which may exceed the capabilities of both human planners and computer equipment. Thus, the demand for more intelligent planning procedures arises.

# 4 VISION OF INTELLIGENT MATERIAL HANDLING PLANNING SYSTEMS

Although planning procedures and knowledge-based decision support systems may help to structure the planning process, the planning results are still highly dependent on the expertise of the planner.

Intelligent algorithms may help to increase both planning efficiency and effectiveness. With this intelligence being software-based, artificial intelligence would be applied in the planning process.

Following the considerations on a definition of artificial intelligence presented in [13], artificially intelligent planning systems (IPS) would be able to generate reasonable and comprehensible decisions on the basis of structured, but a priori unknown data. They could apply selection and compatibility rules, communication protocols, and decision logics to decide which equipment to use for specific processes and to combine in order to form an efficient and effective material handling system.

This also includes the proper combination of devices by analysing compatibilities and overlapping operational areas. Thus, possible configurations of distribution systems can be generated and assessed autonomously on the basis of planning goals and data.

The human planner remains the sole authority to finally choose one alternative to be realised. Table 1 indicates the role of an intelligent planning system in different steps of the material handling planning process.

**Table 1.** Proposed role of intelligent planning systems (IPS)

| Planning step | Description | Role of IPS |
|---|---|---|
| 1 | Planning goals definition | Step supported by IPS |
| 2 | Data basis setup and analysis | Step supported by IPS |
| 3 | Process design | Step processed by IPS |
| 4 | Layout planning | Step processed by IPS |
| 5 | MHES | Step processed by IPS |
| 6 | Detailed planning | - |
| 7 | Bid invitation | - |
| 8 | Start of operations | - |

# 5 STEPS TOWARDS INTELLIGENT PLANNING SYSTEMS

In the remainder of this article, two important issues in overcoming problems in intelligent planning systems are to be addressed:

This includes the setup and analysis of the planning data basis (5.1) as well as the material handing equipment selection and system evaluation (5.2).

## 5.1 Planning data basis setup and analysis

With the quality of the data basis taking high influence on the quality of the planning results, all aspects of creating the planning data basis have to be taken seriously. In order to automatically process input data to a material handling system configuration, reliable and formally described data is necessary. Therefore, different data specific problems require methodical processing:

- Different parts of the planning data basis vary in their duration of validity. Laws or market sizes serve as examples for long-term valid data, whereas products, stock sizes and sales reflect dynamically changing short-term counterparts.
- As planning results highly depend on input data, incorrect data may lead to poor material handling system design. The quality aspect of planning data is furthermore interrelated with the problem of data interpretation and processing: Despite the underlying data quality, missing knowledge, motivation or methodical support may induce the planner to incorrect interpretation and processing. Table 2 serves to highlight the different categories of

planning data quality and its interpretation: If the – according to specified criteria – correct data is correctly interpreted or the incorrectness of data is correctly identified, specific measures can be taken to process the data to promising planning results. In case correct data is incorrectly interpreted or incorrect data is perceived as correct, design shortcomings are likely.

**Table 2.** Data quality and interpretation

| | | interpretation | |
|---|---|---|---|
| | | **correct** | **incorrect** |
| **data** | **correct** | *correct* data is *correctly* interpreted | *correct* data is *incorrectly* interpreted |
| | **incorrect** | *incorrect* data is *correctly* interpreted | *incorrect* data is *incorrectly* interpreted |

Due to the complexity of the planning process, the relationship between input data and planning results cannot be described analytically. New methods have to be developed and applied to ensure an adequate description and processing of input data in the planning process:

- Formal descriptions of the planning process as well as formal descriptions of planning data have to be developed. Thus, vague and qualitative requirements like "flexibility" or "adaptability" can be quantified and automatically processed. Existing approaches that aim to assess qualitative performance of already realised systems (e.g. "agility" in [14]) have to be transformed to *a priori* design methodologies which ensure proper design of systems according to specified qualitative performance requirements. Furthermore, the frequency of usage of different planning data as well as its effect on planning outcome has to be examined.
- As the relationship between data input and planning result cannot be analytically determined, Artificial Neural Networks (ANN) may help to identify data patterns that take high influence on the planning results. Therefore, a new measure has to be developed stating the importance of specific data in the planning process (importance factor). These insights can consequently lead to the derivation of a formal input vector that demands input of all relevant planning data and that can be processed in all consecutive planning phases.

By applying both measures, the frequency of usage as well as the importance of specific planning data can be determined. Table 3 summarises all possible combinations of frequency of usage and importance. Each combination leads to specific actions that have to be taken in the planning process.

Basically, important data has to be analysed and processed more carefully than low-importance-data. In case of limited resources, the frequency of usage may indicate priorities in data handling: This means that important data that is often used has to be analysed and processed with high priority.

To sum it up, shortcomings in data understanding often reject automated data processing. The discussed measures may lead to a better understanding of data relevance and an improved data processing. As a result, the selection of equipment and its integration to an efficient material handling system can be operated by a computer-based design system.

Enabling software planning tools to automatically create and evaluate system configurations nevertheless requires a paradigm shift towards intelligent planning objects, as described in the remainder of this article.

**Table 3.** Data usage and importance

| | | frequency of usage | |
|---|---|---|---|
| | | **high** | **low** |
| **importance** | **high** | Data is *often* used and has *high* influence over planning results | Data is *rarely* used but has *high* influence over planning results |
| | **low** | Data is *often* used but has *low* influence over planning results | Data is *rarely* used and has *low* influence over planning results |

## 5.2 MHES and system evaluation applying Intelligent Planning Objects (IPOs)

Instead of a hierarchic top down selection of equipment, the development of a bottom-up approach is proposed: This approach incorporates Intelligent Planning Objects (IPOs) that mimic properties and behaviour of handling objects, resources, and processes.

Therefore, different IPOs have to be developed: Each IPO represents a specific class of material handling technology (automated guided vehicles (AGVs), order picking technology, conveyors ...) and is equipped with adequate cost and performance assessment methods as well as with relevant strategies. Therefore, resource allocation to specified material handling processes is enabled.

Furthermore, one super-IPO is required to assess the final material handling system configurations as well as to transform user requirements and therefore serves as an interface to the human planner. In a specific planning process, instances of IPO-classes are created that build up a virtual material handling system.

IPOs are able to organise themselves autonomously using defined interfaces and exchange protocols according to a global ontology. The process of material handling systems planning requires a decomposition of user requirements to deviate functions to be carried out in the resulting material handling system, e.g. transhipment of incoming pallets.

Furthermore, the required functions can be organised in different processes: For example, the function "order picking" consists of processes like goods movement, storage, identification, etc.

The concept of IPOs is mainly based on the idea of holons, which have been applied to various industrial problems (e.g. in [15]). Nevertheless, IPOs require a higher level of independence and intelligence than holons, as they have to assess their own role and performance in the desired system on their own.

Our vision is that required functions are processed in a virtual intelligent planning system to deviate processes that can be related to material handling equipment. Then, each IPO evaluates its own compatibility to these processes. In case an IPO is able to execute the required process, the IPO can "block" this process in a virtual IPO marketplace. For example, a conveyor is able to execute a transport process of a transhipment function.

The following three cases may occur:

- *Case 1*: Every deviated process is performed by exactly one allocated IPO. In this case, the next step is generating the connections between all processes.
- *Case 2*: Suppose that $n > 1$ IPOs are able to execute a specific process, different system alternatives are created, e.g. one alternative including conveyors whereas another might include AGVs. Both internal as well as external assessment of the alternatives may help

to reduce the quantity of alternatives. This evaluation requires an *a priori* connection of all processes.

- *Case 3*: A process cannot be executed by one single IPO, but several IPOs contribute to execute the process. Thus, a cluster of these IPO has to be build. For example, the requirements for storing multiple products (light and small vs. large and heavy) cannot be fulfilled by one type of rack. But different types of racks can be combined to store the whole product range. The clusters are built by exchanging structured and formalized messages between the IPO: These messages describe possible combinations of IPOs as well as their specific conditions.

After every process has been assigned to one or more IPO(s), the next step is to combine these IPOs to a material flow system. This combination is moderated by the super-IPO. This IPO builds up and evaluates the connections between the IPOs. As a result, a specific list of possible material handling system configurations is created and presented to the user by the super-IPO.

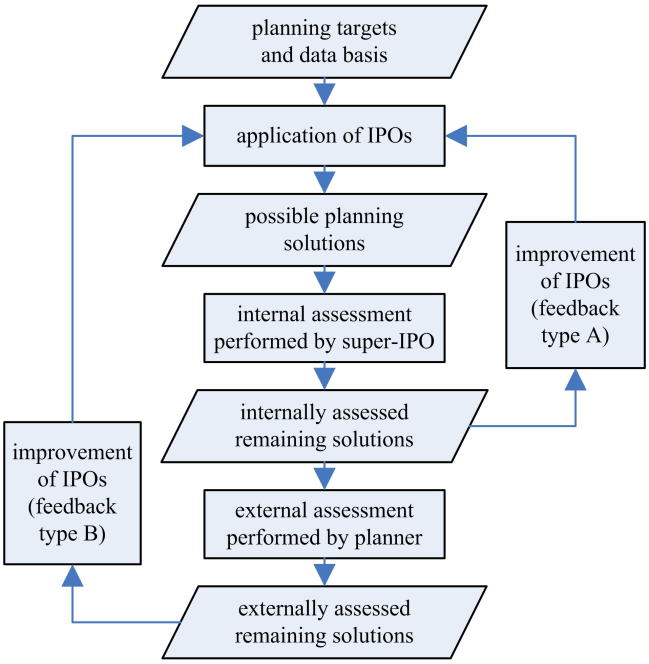


**Figure 1.** Network of transputers and the structure of individual processes

The resulting alternative system configurations are to be assessed according to specific criteria. Intelligence is incorporated by installing two logical feedback types (see Figure 1):

*Feedback type A*: By internally assessing different possible alternative system configurations, inferior ones are analysed automatically to avoid them being proposed in further planning projects.

*Feedback type B*: Proposed configurations are externally assessed by the human planner. In case a generated solution is inferior according to the planner's criteria, his assessment has to be translated into a language processable by the IPO system. The planner has to describe his reasons in a structured message.

By implementing analysis rules into the super-IPO, this information can be incorporated to deduce new IPO internal configuration rules. It is important to reduce the number of alternatives presented to the human planner in order to increase the applicability of this feedback type.

As a third feedback type, benchmarking of realised material handling systems (e.g. on the basis of operating data) may help to validate and improve the theoretical alternative assessment method.

# 6 CONCLUSION AND OUTLOOK

To enable efficient material handling systems planning, different methods and tools aim to support the human planner in finding superior alternatives. Incorporating them into more powerful planning systems may help to reduce uncertainty in the planning process.

In this article, two steps towards intelligent planning systems were discussed: Methods to ensure high quality planning data as well as Intelligent Planning Objects (IPOs) that propose promising configurations to the planner. IPOs may be applied to both initial designs as well as reconfigurations of material handling systems.

These approaches require significant progress in different research fields: First of all, the dependencies between input data and planning results have to be investigated and formalised. This is especially important, as the applicability of IPOs depends on relevant and reliable planning data. Moreover, the sensitivity of planning results can be determined according to their planning input data.

Another field of research is the complex MHES problem. Although isolated methodologies for equipment selection have been developed, a holistic approach that covers interactions between different equipment types is not known yet. In this respect, an ontology for material handling systems is required to enable a communication between digital entities of equipment types.

The most complex part of research is the required intelligence of the IPOs. Both feedback types illustrated in Figure 1 increase the requirements for the ontology. Every feedback of the logistics planner has to be translated into the IPO communication language (ontology) as IPO have to interpret the information contained in each feedback and adapt it to the specified system evaluation methods.

To sum it up, the vision of intelligent planning systems for material handling is promising in finding superior system configurations. The two discussed approaches indicate required progress in different research fields. The human planner benefits in every case from being supported in complex decisions by learning systems.

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