Process-based planning of material handling in manufacturing systems

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Abstract. Manufacturing processes are more and more complicated which requires complex and flexible material handling solutions. The design of material handling for the advanced manufacturing processes can be realized in different ways, but none of them offers generally usable solutions. An integrated design process gives the best device for the planning, but its very complex characterisation makes the application too hard. To make an easier useable design method, which is closer to the operation process of the manufacturing system, we introduce a new planning concept for the material handling. This new concept uses the integrated, task-based approach however; it is mainly focusing to the handling processes. The objective of this concept is not the selection of the optimal solution; it targets to build effective, followable handling processes. In this paper, we describe the new concept and present a scenario to understand its operation.

1. Introduction

Suited to the higher requirement of the customers, the production processes are more and more complicated, so all the solutions (control, material handling, maintenance, etc.) which are applied related to them also have to be more complex. Among others, new, advanced handling processes required to build highly productive, flexible manufacturing systems.

Of course, these changings influence not only the applied machines, but the planning process of the handling solutions.

The design of material handling for manufacturing processes can be realized in different ways, but none of them offers generally usable solutions. An integrated design process gives the best device for the planning, but its very complex characterization makes the application too hard. The objective of our research to make an easier useable design method, which is closer to the operation process of the manufacturing system and let the users to follow the method in every detail. This task requires a new concept in the aspect of the planning process, which will be presented in this paper.

2. Planning of material handling in manufacturing systems - literature review

There are many proved and frequently applied methods for planning of material handling devices, in generally with computer aid [1]. In case of certain machines (forklifts, cranes, etc.), the producers offer standard, exact variations to select, so the planning process is simplified to a selection procedure and a simple application [2]. This is also valid for complex handling systems (monorails, conveyors, etc.), where the required solutions can be built from exact, predefined modules [3]. So, we can say, that the planning or selection of a single material handling machine or a simple handling system is
easily realized by the known methods and devices (dimensioning processes, catalogues, software, etc.).

The problem, that most of the production processes need complex material handling solution, which applies more than one machine types, where the planning process is much more complicated. In this case, the application of a simple planning method is not suitable, because the integration and harmonization of the different machines also must be solved during the planning process. The solution of this situation requires the application of the system concept and system planning [4].

2.1. Material handling systems
Material handling system means a handling solution where more than one handling machines or module elements are applied for different handling processes. These systems, in generally, integrate the specifications of the individual material handling machines, but in certain cases, new specifications can be appeared during the integrated operation [5].

The handling systems can be significantly different depends on the system elements and their relations, but the main difference is the physical scale of the system [6], which can be

- internal handling systems (intra-logistics),
- external handling systems (inter-logistics) and
- workplace handling systems.

Because of the differences among the system types, the planning and operation processes are also different, at this paper we are focusing on the internal handling systems, the others are out of our scope.

In internal handling systems, handling processes operate within a restricted (usually indoor) area and the distances among the objects (manufacturing machines, workplaces, etc.) are short. Important characterization of the system is the exact input and output point, where it can connect to other systems. In these systems, transport routes and rules are flexible and suited to the requirements of the production process [7].

2.2. Planning of handling systems
During the planning of material handling systems, we are looking for suitable handling devices for complex handling processes and harmonize their operation. In the literature two basic solutions exist, which are the task-based and system-based approaches.

In system-based approach, we are analyzing the whole system and looking for a similar, existing one to apply its handling solutions to our system [8]. Similarity of the system can be found in objects, handling tasks, technology or handling devices. During the planning, we are searching in a special database for a similar system-structure and trying to adapt its handling solutions. To realize this planning concept, we need a special database, which are built on certain system types [9]. Typical application of this approach is the duplication of production processes, which is used by multinational companies to multiply their production [10].

In task-based approach, we realize the planning with the using of different individual planning tasks (facility planning, route planning, etc.). Main advantage of this approach is the using of the material-flow parameters, which enables exact, mathematically described calculations. This approach is much better published and used in the practice, but the application in complex systems is not so easy.

Main problems of this approach are the large number of the planning tasks, their complexity and the iterative solution process (Figure 1), which result three different application cases in the practice: single-task planning, multiple-task planning and integrated planning process.

During single-task planning we can solve only one planning task (e. g. [11]) in any kind of system. The complexity of the solution method depends on the scale of the handling system. There are three advanced methods to realize single-task planning in complex systems: Knowledge-Based Engineering [12], Computer Aided Design [13] and Simulation Software [14].
Multiple-task planning means the solving of a group of planning tasks, where usually the methods for the single-task are used, but this concept is basically more complex for any system [15].

Integrated planning tries to solve all the planning tasks in one process, but because of the large number of the tasks and the iterative procedure it is usable only for simple handling systems [16].

Large, complex production systems require advanced, computerized procedures to plan the handling system, which means in generally, an automated optimization. However, as it was described above, because of the complexity of the production system and the planning processes, there is no chance to make a generally usable method for this purpose. There are different initiatives to solve these problems using different software [17], but none of them gives general solution, and because of the complexity level, users cannot look into their operation method and understand its steps.

An integrated design process gives the best device for the planning, but its very complex characterization makes the application too hard. To make an easier usable design method, which is closer to the operation process of the manufacturing system, we introduce a new planning concept for the material handling.

3. Process-based planning: a new concept
To avoid the disadvantages of the above-mentioned planning processes, we are looking for another solution, which is easily understandable and user friend, and can be applied in every handling situation. This new concept uses the integrated, task-based approach however; it is mainly focusing to the handling processes. The objective of this concept is not the selection of the optimal solution; it targets to build effective, followable handling processes.

During this concept, we use the steps of the task-based planning approach but develop a simple procedure for all of them and link them into a chain as it can see in Figure 2.

The individual steps of the planning concept can be linked into different blocks, which determines certain parameters of the material handling system. The main blocks are: determination of the relations, device preselection, building of handling processes, dimensioning and scheduling.

As the methods and realizations of the dimensioning and scheduling of the handling machines are the same as in any other planning concept, in this paper we are dealing only with the first three blocks, the others are out of our research scope.

Figure 1. Structure and steps of the integrated planning
3.1. Determination of the handling relations

Materials handling relation means a special connection between two objects (production or service objects) which involves any kind of handling activity. Handling relations can be defined by the two linked objects and at least one handling parameter (quantities, distances, costs, etc.) existing among them [6].

In the aspect of handling requirements, handling relations can be always described between one source and one destination object. There are some differences within the relations depend on the role of the handling process, because at the realization of the handling tasks we can also determine relations between two sources or two destination objects (e.g. collection systems) [18].

Materials handling relations can be defined and demonstrated by different methods, e.g. handling process charts, material handling graphs, material handling matrices, etc. In generally material handling matrix is used to involve the data of the handling relations, but to demonstrate the structure we also can use a graph. Main advantage of the materials handling matrices, that certain parameters of the handling process can be easily calculated by matrix-operations (e.g. the analysis of the rows of the matrix gives information about the source objects, etc.) [19]. The best way for the analytical determination of the handling relations is the application of the method defined in [20], but other solutions can also be used.

3.2. Device preselection

Main objective of the device selection is to choose the best material handling solution for all the individual handling relations. During the selection process the optimal solution is searched along a given objective function with the comparison of parameters of the materials handling devices and the given relation. Materials handling parameters can be exclusion-type, limitation-type or numerical parameters [21].
Exclusion-type parameters can exclude the application of certain equipment types (for example: roller conveyor cannot be used for bulk solids). They can be unambiguous exclusions (function, goods type, etc.) and definable exclusions (operation characteristic, handling method, track-line, etc.).

Limitation-type parameters do not exclude equipment types, but they can narrow their practical application field (for example: forklifts cannot be used for small boxes). They can be numerical limitations (goods parameters, task parameters, etc.) and not numerical limitations (object parameters, track parameters, etc.).

Numerical parameters are the bases of the analytic design process, their values can be different at the different materials handling machines. Equipment can also be qualified based on numerical parameters using special formulas (see [16]).

In this phase of the process-based planning, we cannot find the best version, but we can narrow the applicable types.

In certain cases, depend on the handled goods, different devices can be applied for the different units linked to the given relation. In this case, parallel independent preselection or uniform unit loads have to be applied.

3.3. Building of handling processes

Material handling process means a given set of handling tasks which are linked to each other suited to a certain logic. The logic of the allocation can be production order, handling specifications, location limits, etc. In generally the material handling system of a manufacturing procedure is built form different linked or independent handling processes (Figure 3).

![Figure 3. Building of a material handling system](image)

During the building of handling processes we are looking for those relations which can be linked into one process. The selection procedure is based on different parameters of the handling relations:

- continuity of the handling process,
- parameters of the handled units,
- location of the objects,
- time-requirement of the relation,
- applicable machines, etc.

Based on the parameters of the material handling relations, the process-building can be realized in the following steps:

1. Building of handling unit categories
2. Building of process variations based on the device types
3. Application of location limits/location planning
4. Calculation of the required performances/capacities
5. Selection of the best solutions/optimization
6. System building from the processes

3.3.1. Building of handling unit categories. The first step of the process building is a grouping based on the parameters of the handled units. The main objective of this activity is to discover the similarities of the handled unit types which can help to realize a uniform handling concept.

The most characteristic differences exist among the three main handled material/element categories (Figure 4), which are
- the raw materials and elements for the manufacturing objects,
- the interoperation semi-finished units produced by the manufacturing objects,
- the finished products.

Units related to these categories are handled in independent processes usually individual handling machines, which can be significantly different (e. g. forklifts for the elements and roller conveyors for the semi-finished units).

Within the categories above, further subgroups can be created depends on the handling parameters, e. g. size, handling solution, etc. These sub-categories can help to select the suitable devices for a given handling process. Another result of this grouping can be the uniformization of the unit-loads, which can reduce the inhomogeneity of the goods and the handling devices.

![Diagram](image)

**Figure 4.** Example for the handling unit categories

3.3.2. Building of process variations. Within the above determined unit categories, we can build process variations using the material handling solutions preselected to the individual handling relations. This activity largely depends on the number of the handling relations and the complexity of the manufacturing system. In case of a simple system, it can be easy to realize, and we can get effective solutions, but complex systems require complicated optimisation methods.

In the aspect of the continuity, handling processes can be continuous or discontinuous. Discontinuous processes contain individual handling tasks where waiting phases can be appeared between the working phases. In this case machines move unit loads and workplace stores are required. During a continuous handling process, there are no waiting between the phases, and the moving of the units (usually pieces or bulk solids) is constant, periodic or stochastic in time.

In the aspect of the process building, handling machines have to be fitted in time and handling specifications.
Handling processes can apply three different machine allocations:
- linking one device to one process,
- linking one device to more than one processes,
- linking more than one device to one process.

The best solution is when one machine works in one handling process, so during the process-building we try to find such solution. However, in many of the cases, material handling machines have too few or much capacity to fulfill this expectation, so we need to take other relation parameters into consideration during the process building.

Important element of the process building is the capacity analyses of the machines, which can reduce the number of the applicable equipment types, because of the capacity limits and efficiency. Usually the main goal of the process building is the cost requirement of the processes, but it depends on different changing factors (e.g. local environment, economic situations, fuel prices).

3.3.3. Application of location limits. The location of the manufacturing objects influences the allocation of the process elements. During the planning of the handling system we can meet two different cases:
- locations of the objects are known,
- locations of the objects must be determined.

If we know the location data during the planning process, then we have to take them as a limit into consideration. It means that we have to modify the process allocations, if some relations are out of the effective area of a handling machine. In this case, we have to repeat the process allocation in all affected processes.

If the location data of the manufacturing objects are not fix at the beginning, we have to determine them during the planning process. The best solution if we select locations for the objects suited to the handling processes. In this case the handling performance requirement will be low. Other possibility is to apply a facility planning optimization procedure [8], which gives an optimal result for its objective function, but cannot take the handling processes into consideration.

3.3.4. Calculation of the required performances. In the knowledge of the handling processes, the required capacity of the applied machines can be calculated. The calculation procedure is different for continuous and discontinuous handling machines.

At continuous material handling equipment (e.g. conveyors), where usually one machine is applied for one process, capacity means a minimal transport performance along the track-line, in many of the cases these are the velocity and a machine specific transport parameter (cross section area, car distance, etc.) of the handling equipment.

At discontinuous machines (forklift, crane, etc.), the handling capacity of the equipment is a constant maximal value, so the objective of the calculation is to determine the required number of the machines for all the handling processes. In generally, the processes cannot use all the total capacity of all machines allocated to them, so some free capacity remained, which can be shared among the other processes if required.

3.3.5. Selection of the best solutions. As a result of the process-building, we have got several process variations, which fulfil the expected requirements, but only one of them can be applied in the manufacturing system. Next step of the planning process is to compare the variations and select the optimal one. For the comparison, numerical parameters must be applied, which can be
- material handling performance,
- handling costs,
- transport distances, etc.
Using the required parameter as an objective function, the calculation can be realized, and the results can be compared to choose the optimal version. If there are no significant differences among the variations in the numerical values, other parameters can be considered to select the best processes.

3.3.6. System building from the processes. Handling systems consist of different handling processes, which can be different relation in each other. To operate the system, we need to determine the relations among the individual processes. Processes can be linked differently, so at the locations, where they meet (objects, locations, tasks, etc.) the parameters of the different processes must be harmonized.

In the meeting points of the handling processes, depends on the parameters of the applied machines, some special technical solution must be used to avoid joining problems (transfer, storing, etc.).

In another case, when one handling machine is used in two or more handling processes, the relation can affect the operation of the individual processes.

4. Scenario for the process-based planning
To demonstrate the process-based planning, in this chapter we present an example to determine the details of the handling system for a production hall. Of course, there is only a simple manufacturing process with static production requirement and easy understandable relations to explain the operation of this new planning concept.

4.1. Manufacturing objects and production data
In our simple example we analyze a production process with 8 manufacturing machines, 3 final product types and unit handling. Figure 5 shows the graph-structure [22] of the manufacturing objects and the scaled production processes for the different products.

![Figure 5. Manufacturing objects and their relations](image-url)

The production sequence for all the final products and the required element types can be followed in Figure 6, Table 1 involves the data for the objects and the products.
Figure 6. Production sequence for the three product types

Table 1. Production parameters

| Products       | Produced quantities [pcs/h] | Element needs at the objects [pcs/unit] |
|----------------|----------------------------|-----------------------------------------|
|                | O1 | O2 | O3 | O4 | O5 | O6 | O7 | O8 |
| 1. Product a)  | 30 | x  | x  | x  |    |    |    |    |
| elements       | a1 | a2 | a3 |    |    |    |    |    |
| quantities     | 1  | 2  | 1  |    |    |    |    |    |
| 2. Product b)  | 50 | x  | x  | x  |    |    |    |    |
| elements       | a4 | a5 |    |    |    |    |    |    |
| quantities     | 1  | 1  |    |    |    |    |    |    |
| 3. Product c)  | 20 | x  | x  | x  | x  |    |    |    |
| elements       | a4 | a5 | a6 | a7 |    |    |    |    |
| quantities     | 1  | 1  | 3  | 1  |    |    |    |    |

4.2. Material handling relations
Based on the production data, using the method defined in [20], we can calculate the parameters of the material handling relations among the system objects. At our scenario we used the MHRelCalcV1.0 software (described in [23]) to calculate the relation matrix of the analyzed system (Table 2). To follow the material flow of the different element/unit types, a material handling graph also presented in Figure 7.
Table 2. Relation matrix  
(ES – element/material store, PS – final product store)

| Objects | ES | O1 | O2 | O3 | O4 | O5 | O6 | O7 | O8 | PS |
|---------|----|----|----|----|----|----|----|----|----|----|
| ES      | 30 | 60 | 30 | 70 | 70 | 60 | 20 |    |    |    |
| O1      |    | 30 |    |    |    |    |    |    |    |    |
| O2      |    | 30 |    |    |    |    |    |    |    |    |
| O3      |    |    |    | 30 |    |    |    |    |    |    |
| O4      |    |    |    |    | 70 |    |    |    |    |    |
| O5      |    |    |    |    |    | 50 | 20 |    |    |    |
| O6      |    |    |    |    |    |    |    | 80 |    |    |
| O7      |    |    |    |    |    |    |    |    | 20 |    |
| O8      |    |    |    |    |    |    |    |    |    | 20 |
| PS      |    |    |    |    |    |    |    |    |    |    |

Figure 7. System objects and their relations

4.3. Device preselection

To determine the applicable solutions for the handling process, at first, we have to define the parameters of the individual relations, which described in Table 3.

Required operations of the given relation are depends on the technical structure of the related objects, at internal handling systems they can be

- transportation (if the distance is longer than the range of a loader machine),
- loading (if any or both objects requires loading activities),
- storing (if any or both objects cannot accept the goods directly).
Table 3. Parameters of the relations

(Y – yes, N – no, US – upper-side, DS – down-side, FS – front-side, AS – all-side, S – supporting, H – hanging, P – pressing, Box – box limit, Pal – palette limit, Any – no described)

| Relations     | Goods Type | Quantity [pcs] | Operations | Handling | Route |
|---------------|------------|----------------|------------|----------|-------|
| ES→O1         | a1         | 30             | Y          | Y        | Y     | Any   | FS   | Bx   | 20   | N    | 1     |
| ES→O2         | a2         | 60             | Y          | Y        | Y     | Any   | FS   | Bx   | 20   | N    | 1     |
| ES→O3         | a3         | 30             | Y          | Y        | Y     | Any   | FS   | Bx   | 25   | N    | 1     |
| ES→O4         | a4         | 70             | Y          | Y        | Y     | Any   | FS   | Bx   | 15   | N    | 1     |
| ES→O5         | a5         | 70             | Y          | Y        | Y     | Any   | FS   | Bx   | 15   | N    | 1     |
| ES→O7         | a6         | 60             | Y          | Y        | Y     | Any   | FS   | Bx   | 20   | N    | 1     |
| ES→O8         | a7         | 20             | Y          | Y        | Y     | Any   | FS   | Bx   | 20   | N    | 1     |
| O1→O2         | F1         | 30             | Y          | N        | N     | Any   | FS   | Bx   | 5    | N    | 1     |
| O2→O3         | F2         | 30             | Y          | N        | N     | Any   | FS   | -    | 5    | N    | 1     |
| O3→O6         | F3         | 30             | Y          | N        | N     | Any   | FS   | -    | 5    | N    | 1     |
| O4→O5         | F4         | 70             | Y          | N        | N     | Any   | FS   | Bx   | 5    | N    | 1     |
| O5→O6         | F5         | 50             | Y          | N        | N     | Any   | FS   | -    | 8    | N    | 1     |
| O5→O7         | F9         | 20             | Y          | N        | N     | Any   | FS   | -    | 5    | N    | 1     |
| O7→O8         | F7         | 20             | Y          | N        | N     | Any   | FS   | -    | 5    | N    | 1     |
| O6→PS         | F6         | 30             | Y          | Y        | Y     | S     | FS   | Pal  | 15   | N    | 1     |
|               | F10        | 50             | Y          | Y        | Y     | S     | FS   | Pal  | 15   | N    | 1     |
| O8→PS         | F8         | 20             | Y          | Y        | Y     | S     | FS   | Pal  | 15   | N    | 1     |

The determinative handling characterizations of the objects within a given relation can be
- grabbing (supporting, hanging, pressing, etc.),
- reaching (usually upside, downside or frontside),
- size-limits (can be minimal, maximal, palette-size, box-size, etc.).

The route parameters of the relations can be physical (distance and fall) or complexity characterizations. Complexity of a relation depends on the number, directions (horizontal, vertical, slopes, arcs, etc.), angles and connections of the line-sections of the routes. It can be described by a number (e.g. 1-9), which are defined previously based on the system parameters.

In our scenario, two size-limits exist:
- at all the objects workplace stores are required, where the elements can be placed only in boxes with a given size,
• final products are transported on standard palettes into the product store.

If we described the parameters of the relations, next step is to compare them to the parameters of the handling machines (Table 4).

**Table 4.** Important selection parameters of material handling machines for unit handling
(Y – yes, N – no, US – upper-side, DS – down-side, FS – front-side, AS – all-side, S – supporting, H – hanging, P – pressing, Box – box limit, Pal – palette limit)

| Handling machines | Direction | Functions | Handling | Line |
|-------------------|-----------|-----------|----------|------|
|                   | Horizontal| Vertical  | Transport| Loading| Storing| Grabbing| Reaching| Size limit| Free | 1 track | More track |
| Forklifts         | Y         | Y         | Y        | Y      | N      | S       | FS      | Pal     | Y    | N       | N         |
| Platform trucks   | Y         | N         | Y        | N      | Y      | -       | -       | -       | Y    | N       | N         |
| Travelling cranes | Y         | Y         | Y        | Y      | N      | H       | US      | -       | N    | N       | Y         |
| Hoists            | Y         | Y         | Y        | Y      | N      | H       | US      | -       | N    | Y       | N         |
| Jib cranes        | Y         | Y         | N        | Y      | N      | H       | US      | -       | Y    | N       | N         |
| Monorails         | Y         | Y         | N        | Y      | Y      | -       | US      | -       | N    | Y       | N         |
| Robots            | Y         | Y         | N        | Y      | N      | P       | AS      | -       | Y    | N       | N         |
| Storage-retrieval machines | Y   | Y   | N   | Y   | N    | S      | FS     | Bx    | N    | N      | Y         |
| Elevators         | N         | Y         | Y        | N      | N      | -       | -       | -       | N    | Y       | N         |
| Tow conveyors     | Y         | Y         | Y        | N      | N      | -       | US      | -       | N    | Y       | N         |
| Trolley conveyors | Y         | Y         | Y        | N      | N      | -       | US      | -       | N    | Y       | N         |
| Roller conveyors  | Y         | Y         | Y        | N      | Y      | -       | -       | -       | N    | Y       | N         |
| Belt conveyors    | Y         | Y         | Y        | N      | N      | -       | -       | -       | N    | Y       | N         |

Using the data in Table 3 and 4 we can determine the applicable equipment types for the individual relations. Table 5 contains the best solutions for our test system.

4.4. Process building
As it described in Chapter 3.3, the first step of the process building is the analysis of the units handled in the system. In our scenario we have three main unit types (elements – a1-a7, processed units – F1-F5, F7, F9 and finished products – F6, F8, F10). Elements and products have uniform handling parameters, but we can determine differences within the half-finished units:

- F1 and F4 are handled in given sized boxes,
- F2, F3, F5, F7 and F9 can be handled in boxes or in palettes.

The simplest case is the handling of the final products, where only one machine type is suitable (forklift), so at this phase, we can define one handling process which contain both relations (O6→PS and O8→PS).
Table 5. Applicable machines for the handling relations

| Relations | Forklifts | Platform trucks + ML | Travelling cranes | Hoists | Jib cranes | Monorails | Robots | Storage-retrieval machines | Elevators | Tow conveyors | Trolley conveyors | Roller conveyors + ML | Belt conveyors + ML |
|-----------|-----------|-----------------------|-------------------|--------|------------|-----------|--------|-----------------------------|-----------|---------------|---------------------|-----------------------|----------------------|
| ES→O1     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| ES→O2     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| ES→O3     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| ES→O4     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| ES→O5     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| ES→O7     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| ES→O8     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O1→O2     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O2→O3     | x x       |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O3→O6     | x x       |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O4→O5     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O5→O6     | x x       |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O5→O7     | x x       |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O7→O8     | x x       |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O6→PS     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |
| O8→PS     | x         |                      |                   |        |            |           |        |                             |           |               |                     |                       |                     |

4.4.1. Handling processes of the elements. As we can observe in Table 5, we can use three types of equipment for the transportation of the elements to the manufacturing objects. All three (platform truck, belt conveyor and roller conveyor) is suitable for the handling with manual loading of the boxes. To make process variations, we have to analyse the locations of the related objects (Figure 8.) and the transportation parameters (Table 6).

It can be seen in Figure 8 that the location of the supplied objects is dispersed on a larger area and they cannot be linked by a simple transport line, so the application of fixed-line equipment is not the best solution, because of the complex transport routes.

It is easy to see, if we apply a palette car with 0,8m x 1,2m (placed only 6 boxes on it in one route) platform, the total amount of the boxes (see Table 6) can be easily transported within one hour using even the simplest direct routes (one transport and one empty return per relation) for the supply. As the
total length of the routes is over 40 m, the application of any of the continuous handling equipment (belt and roller conveyors) could be more expensive than a single palette car. Beside it, the complexity and manual handling service of them can also be problematic.

**Figure 8.** Objects and a road-variation in the element supply process

**Table 6.** Transportation parameters in the element supply process

| Relation | Element | Type | Quantity | Unit | Content | Size A | Size B | Size C | Quantity | Distance |
|----------|---------|------|----------|------|---------|-------|-------|-------|----------|----------|
| ES→O1    | a1      | [pcs]| 30       | Bx   | 10      | 0,4   | 0,4   | 0,4   | 3        | 20       |
| ES→O2    | a2      | [pcs]| 60       | Bx   | 20      | 0,4   | 0,4   | 0,4   | 3        | 20       |
| ES→O3    | a3      | [pcs]| 30       | Bx   | 10      | 0,4   | 0,4   | 0,4   | 3        | 25       |
| ES→O4    | a4      | [pcs]| 70       | Bx   | 10      | 0,4   | 0,4   | 0,4   | 7        | 15       |
| ES→O5    | a5      | [pcs]| 70       | Bx   | 7       | 0,4   | 0,4   | 0,4   | 10       | 15       |
| ES→O7    | a6      | [pcs]| 60       | Bx   | 20      | 0,4   | 0,4   | 0,4   | 3        | 20       |
| ES→O8    | a7      | [pcs]| 20       | Bx   | 5       | 0,4   | 0,4   | 0,4   | 4        | 20       |
| **Total**|         |       |          |      |         |       |       |       |          | 33       |

**4.4.2. Handling processes of half-finished units.** As it can be seen in Table 5, theoretically there are four device alternatives for the interoperation handling. Of course, we can apply different combinations of them, but at first, we are analysing the one-device handling possibilities.

If we use only one machines for the handling, we have three main solution possibilities:
- handling boxes in all the relations,
- handling boxes (in two relations) and palettes (in five relations),
- handling boxes (in two relations) and pieces (in five relations).
As our main goal is the minimalization of the number of the handling machines, the starting case is the uniform handling in boxes. Table 7 shows the transportation parameters of the handling of the boxes among the system objects.

Table 7. Transportation parameters of the interoperation handling

| Relation | Unit | Quantity | Type | Content | Size A | Size B | Size C | Quantity | Distance |
|----------|------|----------|------|---------|--------|--------|--------|----------|----------|
|          |      |          |      |         | [pcs]  | [pcs]  | [m]    | [pcs]    | [m]      |
| O1→O2   | F1   | 30       | Bx   | 10      | 0,4    | 0,4    | 0,4    | 3        | 5        |
| O2→O3   | F2   | 30       | Bx   | 10      | 0,4    | 0,4    | 0,4    | 3        | 5        |
| O3→O6   | F3   | 30       | Bx   | 6       | 0,4    | 0,4    | 0,4    | 5        | 7        |
| O4→O5   | F4   | 70       | Bx   | 10      | 0,4    | 0,4    | 0,4    | 7        | 5        |
| O5→O6   | F5   | 50       | Bx   | 10      | 0,4    | 0,4    | 0,4    | 5        | 8        |
| O5→O7   | F9   | 20       | Bx   | 5       | 0,4    | 0,4    | 0,4    | 4        | 14       |
| O7→O8   | F7   | 20       | Bx   | 5       | 0,4    | 0,4    | 0,4    | 4        | 5        |
| Total   |      | 31       |      |         |        |        |        |          |          |

As in the element supply, we can apply a palette car with 0,8m x 1,2m platform, the total amount of the boxes (see Table 6) can be transported within one hour using even the simplest direct routes. The total length of the routes (see Figure 9) is fewer than at the element supply, but the application of a continuous handling equipment could be more expensive than a single palette car.

As one palette car is enough to handle all the relations, it is not worth to analyze the other versions, and the best solution will be finalized during the system building phase.
4.5. System building

During the system building, usually the final handling processes are detailed and harmonized, but in our scenario the finalization will be actualized.

The result of the process building for the analyzed system is three different process using two different machines (forklift and palette car). As two of the processes use the same machine type and their capacity use are near 15%, so it is possible to realize them with the same machine.

Of course, the planning will only be completed, if the dimensioning of the machines and the scheduling of the routes are made, but these procedures are out of the scope of our paper.

The applied process of our simple system can be seen in Figure 10.

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**Figure 10.** Handling system for the example production procedure

5. Conclusions

As the production processes are more and more complicated, which requires complex and flexible material handling solutions, the used design methods of material handling cannot offer generally usable solutions. Many computer methods try to follow the increased requirements, but they are dealing with only some part of the design tasks and in generally their procedures are not enough clear and understandable.

The objective of our research to develop a new planning concept for the materials handling, which is clear and followable for the users and gives effective results. Of course, this method cannot give global optimal solutions, but tries to find the best variation among many analyzed versions. The new concept uses the integrated, task-based approach however; it is mainly focusing to the handling processes.

In this paper, we described the new concept and presented a simple scenario to understand its operation.

The critical point of this concept is the process building, so to use this method in the practice, we have to develop an exact procedure which can be applied for the design of most of the handling systems. After it the next step will be to use computer methods to realize the process steps.

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References

[1] Wang J. Y., Zhao J. S., Chu F. L. and Feng Z. J. 2010 Innovative design of the lifting mechanisms for forklift trucks. Mechanism and Machine Theory 45 12, 1892-96
[2] Olearczyk J., Al-Hussein M. and Bouferguène A. 2014 Evolution of the crane selection and on-
site utilization process for modular construction multi-lifts. *Automation in Construction* **43**, 59-72

[3] Fonseca D. J., Uppal G. and Greene T. J. 2004 A knowledge-based system for conveyor equipment selection. *Expert Systems with Applications* **26** 4, 615-23

[4] Apple J. M. 1972 *Materials Handling Systems Design*. Ronald Press: New York

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

[6] Cselényi J. and Illés, B. (eds.) 2006 Design and control of material flow systems 1. (in Hungarian). University Press: Miskolc

[7] Telek P. 2012 Variations of material handling systems (in Hungarian). *GÉP* **63** 4, 23-26

[8] Bánya T. 2012 Structured modelling of integrated material flow systems (in Hungarian). *GÉP* **63** 4, 83-86

[9] Telek P. 2011 Characteristic solutions of material flow systems. *Advanced Logistic Systems - Theory and Practice* **5**, 57-62

[10] Antoniolli I., Guariente P., Pereira T., Pinto Ferreira L. and Silva F. J. G. 2017 Standardization and optimization of an automotive components production line. *Procedia Manufacturing* **13**, 1120-27

[11] Jiang S. and Nee A. Y. C. 2013 A novel facility layout planning and optimization methodology. *CIRP Annals - Manufacturing Technology* **62**, 483-86

[12] Landschuetzer C., Jodin D. and Wolfschlockner A. 2011 Knowledge Based Engineering – an approach via automated design of storage/retrieval systems. *Proceedings in Manufacturing Systems* **6** 1, 3-10

[13] Sugimoto Y., Seki H., Samo T. and Nakamitsu N. 2016 4D CAD-based evaluation system for crane deployment plans in construction of nuclear power plants. *Automation in Construction* **71** 1, 87-98

[14] Bažid K., Ćuković S., Iqbal J., Yousnadj A., Chellali R., Meddahi A., Devedžić G. and Ghionea I. 2016 IROSim: Industrial Robotics Simulation Design Planning and Optimization platform based on CAD and knowledgeware technologies. *Robotics and Computer-Integrated Manufacturing* **42**, 121-34

[15] Ortner-Pichler A. and Landschützer C. 2017. Improving geometry manipulation capabilities of Knowledge-based Engineering applications by the versatile integration of 3D-CAD systems. In *CD proc. of MultiScience - XXXI. microCAD Int. Multidiscipl. Sci. Conf. (C1: Log. section, 3.)*, University of Miskolc

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

[17] Welgama P. S. and Gibson P. R. 1995 A Hybrid Knowledge Based/Optimisation System for automated Selection of Materials Handling System. *Computers Ind. Engrg.* **28** 2, 205-17

[18] Cselényi J. and Telek P. 1999 Mathematical modelling of collecting logistic system of used electronic products, In: *Bánya T. and Cselényi J. (eds.) Modelling and optimization of logistic systems: Theory and practice.* University of Miskolc, 1-12.

[19] Obádovics J. Gy. and Szarka, Z. 2009 *Mathematics at higher levels* (in Hungarian). Scholar Publishing: Budapest

[20] Telek P. 2016 Material flow relations in the design process of materials handling. *Advanced Logistic Systems - Theory and Practice* **10** 1, 53-64

[21] Telek P. 2014 Application of device-preselection for discontinuous unit handling. *Advanced Logistic Systems - Theory and Practice* **8** 1, 93-102

[22] Kulcsár B. 1998 *Industrial logistics* (in Hungarian). LSI Education Center: Budapest

[23] Telek P. 2017 Computer Method for the Determination of Materials Handling Relations In: *CD proc. of MultiScience - XXXI. microCAD Int. Multidiscipl. Sci. Conf. (C1: Log. section, 5.)*, University of Miskolc