Advanced Logistic Systems, Vol. 7, No. 1 (2013), pp. 105–110.

COMPLEX DESIGN OF INTEGRATED MATERIAL FLOW SYSTEMS

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Abstract: Material flow systems have in generally very complex structure and relations. During design, building and operation of complex systems there are many different problems. This paper shows some usable solution for the design and selection process of material flow systems. We give a short overview about the theoretical principles of the design process, then describe the base design tasks, the possibilities of the using of heuristic algorithms and the modelling of material flow systems. At the end of the paper we present those evaluation methods which are suitable for material flow systems.
Keywords: material flow systems, design methods, evaluation, modelling, complex processes.

Introduction

A material flow process consists of different building elements, some of them (technology equipment, transmission points etc.) are given for the design tasks and the others (stores, transport lines etc.) have to be determined. The selection of material handling machines is always resulted by a design process.

The design of complex systems is realised in integrated process, which means that not only the internal material flow however the related non material flow tasks (manufacturing or service elements, external material flow objects, etc.) have to be taken into consideration.

In this paper we summarise our research about the theoretical principles and methods of the design of material flow systems. The results are not cover all aspects of the actual research field, but using the developed elements, the design, building and operation of material flow systems can be more effective.

1. Theoretical principles of the design process

Material flow is a simple physical process in which materials, objects or living creatures move along a given channel from one point to another.

The determination of the parameters of the material flow system is based on some basic property which can be defined by a material flow model (Figure 1). If the process elements can be directly related to each other we can defined a simple material flow process, but if we cannot describe direct relations among the objects we have to use a system approaching.

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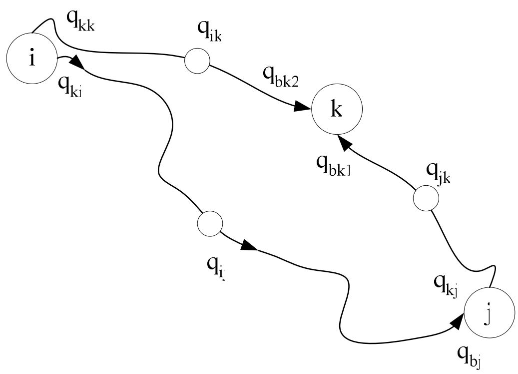

Figure 1. Complex relations among the objects of the material flow processes
$\mathbf{q_{kk}}$ – material flow intensity from object ***k*** [pcs/s],
$\mathbf{q_{ik}}$ – material flow intensity from object ***i*** to object ***k*** [pcs/s],
$\mathbf{q_{bk}}$ – material flow intensity into object ***k*** [pcs/s].

Material flow systems in generally contain four system element types (objects, transport lines, material flows and materials handling devices) and depend on the coverage can be ranged into three different groups [1]:

- serving of manufacturing machines,
- internal material flow systems (for example serving of manufacturing systems),
- external material flow systems (for example traffic systems).

In certain cases material flow systems can be designed by individual solution of given design tasks, but in most of the cases the design tasks are depend on each other, so iterative design process has to be applied.

Design tasks of material flow systems result a certain group of parameters which define the system characteristics based on some input properties. All of the design tasks have similar solution scheme where the aim is to choose the suitable (or the best, if it is possible) system parameters for the required operation conditions.

2. Methods for the design and selection process

There are many possible methods to solve the design tasks of material flow systems. In this paper we present a general description about the traditional solution of the base tasks and the using of heuristic methods. Beside them the modelling of the material flow systems is also an important possibility. As there are several way to realize a given material flow system, we have to use evaluation methods to compare the possible varieties.

2.1. Solving methods for the base tasks. The selection of the applicable design method is depend on the characterisations of the material flow system and the given design task. The most important factors at the selection are the number of the objects taken into consideration and the time function of the material flow processes. If the material flow is simple (nearly constant) and the number of the objects is low, then we can use the simple, traditional methods even with manual calculations. The higher the number of the objects the more calculation is required, however it is solvable using computers. At complex design methods or huge object-set special optimisation methods have to be applied (in most of the cases it gives only approximate results).

Time function of a material flow process can be – in the aspect of the design tasks – constant or changing (deterministic or stochastic) [2].

The simplest case is the constant material flow where the traditional design methods are easily usable and give suitable results. The deterministicaly changing material flow can be also easily designed if the analysed term can be partitioned into constant phases. In this case the situation will be the same as at constant material flow, but the design process will be a little bit longer. The most problematic case is the stochasticaly changing material flow. As the stochastic behaviour can be appeared at more than one objects of the system, so their effects can be superposed during the operation. Of course these problems make the design process more complex.

In certain cases the stochastic character can be replaced by deterministic or constant material flow during all of the term or in some partitions which can help to simplify the tasks. If the stochasticity of the material flow cannot be eliminated we have to use special distribution functions to solve the tasks which give only approximate results.

2.2. Heuristic optimisation methods. In the case of robust systems, networked processes the analytical methods are not always suitable. Designers of large scaled systems and processes use more often heuristic optimization methods and algorithms. Heuristic methods and algorithms make it possible to calculate the optimal (or near-optimal) system parameters of global logistics systems, supply chains and production systems [3, 4, 5].

The design of enterprise systems with mobile robot based material handling system is realised by the aid of heuristic methods because of the complexity of technological and logistic processes. The first phase of the design with heuristic methods is the definition of the objective functions. There are two different types of objective functions:

1. the objective function includes the minimisation of investment costs and the operation cost are not taken into consideration (this objective function is used in the case of a lack of capital);
2. the objective function includes both the investment and the operation costs (amortisation costs).

The next phase of the optimisation process is the definition of operation strategies. The definition of objective functions and operation strategies are interchangeable. There are three types of parameters of the optimisation:

1. parameters defining the problem; they are constant during the optimisation process;
2. parameters defining one specified version of the system; by the aid of these and the parameters of the first group it is possible to define the third type of parameters;
3. output parameters of the design process.

It is subservient to analyse the effect of the parameters (2. group) on the objective functions. This analysis makes it possible to define input parameters to accelerate the algorithm. The GA based algorithm includes the following phase:

1. definition of input parameters (system parameters, parameters of the algorithm, constraints),
2. definition of the first population,
3. using of reproduction operator,

4. calculation of the value of system parameters for each individual,
5. calculation of other parameters for each individual,
6. calculation of system parameters,
7. calculation of the optimal lifetime of the units of the system,
8. calculation of objective function,
9. using of mutation operator,
10. calculation of the average value of the objective function,
11. repeat of the iteration process if necessary.

2.3. Modelling of material flow systems. The aim of the modelling is to make a more simple process which is similar to the original one, to make the real model analysable [6]. All models are created to one special purpose, so different models can belong to one given process. Sometimes the analysis of a complex process can require more than one model which describe different parameters of one process.

Main aim of the modelling of a material flow process is to build a model which can be used in design, control and optimisation tasks. There are three individual levels of the applicable models of materials handling systems:

- operation models of materials handling equipment (served for the examination of the dynamical behaviour, at which problems of the operation can be uncovered),
- models of the base processes of the material flow (used for controlling of realization and operation, it can be very different for loading, transporting, storing, packaging etc.),
- models of complex materials handling processes (in generally contain more than one base processes, the larger the complexity of the processes the most complex model has to be built).

Material flow processes can be analysed using one model (at one objective function) which in generally mathematical, physical or structural models.

In the aspect of modelling, materials handling systems have three significantly different varieties [7]:

- systems can be simplified to one process,
- systems containing changing material flow,
- large systems containing numerous devices and independent tasks.

Material flow systems can be simplified to process models (in small systems), if the material flow is constant in time among the objects and the allocation of the devices is also not changing. In large systems further condition of the simplification is the parallel operation of the sub processes.

If the material flow is changing in time, then there are two possibilities to describe the system model:

- using special objective functions where the effects of the changing parameter can be avoided (for example: using the length of the transport lines instead of the materials handling performance),
- using statistical methods (average values, limit values etc.) for the changing parameter, however it requires previous statistical analysis.

In case of changing material flow the models give only approximate results and reduce the validation fields.

In case of large systems containing numerous devices and independent tasks, it is better to link the objects to certain subfields to define the model and the material flow parameters have to be calculated by statistical methods based on changing values. At these models the results are valid only for the given subfields.

2.4. Evaluation methods for material flow systems. As there are several way to realize a given material flow system, it is important to select the optimal solution. For this selection we have to use evaluation methods to compare and qualify the possible varieties.

Depend on the characterisations of the given processes it can be large differences between the material flow systems. Because of it many of them are not comparable directly so there is important to separate the most characteristic types (internal and external material flow) and different evaluation methods have to be used for them.

Possible evaluation methods for integrated material flow systems are [8]

- performance-based evaluation,
- time-based evaluation,
- device efficiency-based evaluation,
- device exploitage-based evaluation,
- cost-based evaluation.

Comparing the specifications of the evaluation methods (see in [8]), it can be said that all of the methods, except the cost-based, use the same approaching, individually analyse the transport, the loading and the storing elements. The cost-based method, beyond the above mentioned elements, takes also the independent objects and the vacant runs into consideration. There is an important fact that the performance- and the time-based approaching cannot give information about the passive states of the devices.

3. Summary

The aim of this paper was to summarise the results of the researches which related to the basic principles and methods of the design of integrated material flow systems at the Department of Materials Handling and Logistics of the University of Miskolc in the last few years.

We presented the applying possibilities and limits of the traditional design methods, the heuristic algorithms and drew the principles of the modelling of material flow systems. As there are several way to realize a given material flow system, we showed some evaluation methods to compare and qualify the possible varieties which is essential for the selection of the optimal solution.

Of course we could not go into details at the analysed research topics, however our results can help the designers and the operators of the material flow systems to make the industrial processes more efficient.

Acknowledgements

This research was (partially) carried out in the framework of the Center of Excellence of Mechatronics and Logistics at the University of Miskolc.

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