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Warehouse layout problems : Types of problems and solution algorithms

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Abstract

Warehouse design and operation plays an integral role in the whole supply chain system. For this reason, many researchers have dealt with these types of problems not only by mathematically modelled but also by introduced other kinds of solutions such as artificial intelligence. On our paper, we present these two types of solutions (mathematical models and technological solutions) and the types of warehouse layout problems. Our goal is to offer a more structured view for the important problem of warehouse layout problem.

Keywords: Warehouse design, warehouse layout problem, mathematical models

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1 Introduction

Warehouse layout problem is consisted of a variety of problems. The main problems are: storaging, architectural design and general layout problem, picking, response time for the order processing, minimization of travel distances in the warehouse, routing of pickers or automated guided vehicles (AGV), personnel and machine Scheduling, problems related to AS/RS.

Storaging concern problems where quantities of goods must be warehoused in a height with the proposed solutions to give the classes of storaging. Design and general layout problems concern the architectural indoor configuration of the warehouse and propose solutions concerning number of aisles, layout of aisles (parallel, cross, fishbone etc)

Picking problems concern optimization problems of this procedure in relation with the design of the warehouse. Response time for the order processing, minimization problems of the response time for an order processing by the warehouse. This kind of problems is usually solved by stochastic models.

Minimization problems of travel distances in the warehouse concern calculation problems of the shortest path for the points in the warehouse where ordered products are kept. Routing of pickers and automated guided vehicles concern problems which optimally configure each picker‘s travel for the order processing.

Personnel and machine scheduling problems relate to optimization problems of machine and personnel working time and shifts. Problems relating to AS/RS are also optimization problems concerning the operation of AS/RS systems.

2 Solutions for the warehouse layout problems

We discern the solutions for the warehouse layout problems into two types, mathematical based and technological based solutions.

2.1 Technological based solutions

As far as the second type concerns, we find the paper of Hoeih and Tsai [1] on which a software tool is proposed for the solution of warehouse layout problem. Further, on the paper of Yang and Feng fuzzy logic is proposed for the solution of the above mentioned problems [2]. Another type of technological solution is the use of knowledge management tool where is proposed on the paper of Germain et al. [3]. On the study of Yang and Sun [4] an hybrid intelligent algorithm is proposed for the minimisation of the total warehouse transportation cost. Relative to the above mentioned paper, Chen et al [5] propose an intelligent system for warehousing systems. Further, another multiagent system and its architectural design is proposed by Veyns and Holvost [6] for warehousing. Last but not least, an application of fuzzy logic theory in the design of a distribution centre is proposed by Makatosi et al [6].

2.2Mathematical based solutions

This type of solution includes different types of algorithms such as

- Heuristics
- Algorithms based on geometry
- “cut trees” algorithms
- Genetic Algorithms
- Neighbourhood search algorithms
- Dynamic programming
- Linear and non-linear programming
- Mixed integer programming
- Stochastic programming
- Simulated annealing algorithms

- Particle swarm optimization
- General mathematical models
- Other algorithms

Worth to be mentioned that the algorithms of simulated annealing, particle swarm optimization, neighborhood search and genetic algorithms are also called metaheuristics. Further to the above mentioned algorithms which offer solutions to analytical models there are also simulation models which are used to warehouse layout problems.

Before starting to analyze the types of solutions, we have to mention the basic model for warehouse layout problems which is the “cube per index”. The model, although generic, is the basis for this kind of problems. According to Malmborg and Bhaskaran [7] “Cube per order index (COI) is a very widely used rule of thumb for allocating storage space to inventoried items in a warehouse. It is the ratio of the item‘s storage space requirement (cube) to its popularity (number of storage/retrieval requests for the item). The COI based assignment policy ranks the item on the basis of theri COI values in an ascending order and then allocates them in that order to the most accessible locations closest to the input/output (I/O) point”

Heuristics: Heuristics solutions have been frequently applied to warehouse layout problems. Papers offering a heuristic solution is the paper of Larson et al [8] on which a heuristic algorithm offers solution to storaging problem. Another paper is this of Malmborg et al [9] where an evaluation of rule of thumb for warehouse layout is presented. The heuristic offer minimum total inventory and order picking costs. Further, the study of Peterssen [10] evaluates order picking and routing policies using heuristics. Relative to the previous paper is the paper of Peterssen and Schemmer [11] on which an evaluation of routing and volume based storage policies is presented . A heuristic also approach based on the combination of simulated annealing and decomposition method provides the paper of Lai et al.

[12]. Layout evaluation by using heuristics is provided on the paper of Huertas et al. [13]. The layout evaluation concerns large capacity warehouses. Heuristic algorithms are used to shared storage policies on the paper of Goetschalckx and Ratliff [14].Moreover; on the paper of Ashayen et al [15] a simple heuristic for the p-median problems is provided. A heuristic procedure based on dynamic programming formulation is also presented on the study of Rosenblatt [16]. A different kind of heuristics, the graph heuristics is presented on the paper of Kim [17].

Next to the algorithms we present the Algorithms based on geometry. They offered solutions to warehouse layout problems based of the theory of Euclidean space and Lesbesgue according to the study of Cdey and Roberts [18] or they provided solutions for rectangular layout problems according to the study of Thornton et al. [19].

Interesting solution algorithm for warehouse layout problem is the cut tree solution [20] which “is easy to use and very powerful to in aiding designers to generate quality layouts” according to the authors.

Another kind of algorithms is genetic algorithms. Papers dealing with genetic algorithms in relation to layout problems are: the paper of Zhang and Lar[21] on which path relinking and genetic algorithms are combined , the paper of Zhang et al [22] on which genetic algorithms are presented for the solution of multi-level warehouse problems, the paper of Hsu et al [23] which deals with the problem of batching orders and the paper of Wu and Appleton [24] on which the optimization of block layout and aisle structure using genetic algorithms is presented.

Further to genetic algorithms, solutions to warehouse layout problem provide neighborhood search algorithms. The papers of Geng et al [25] and of Ho et al [26] solve the layout problem by using this kind of algorithm. On the first paper a neighborhood search combined with an artificial intelligence tool solve warehouse routing problem whereas the second paper compares two –zone visitation sequencing strategies. The comparison takes place as two-phase optimization process with the first phase a neighborhood search algorithm is applied and on the second phase a simulated annealing algorithm is used.

Next type of algorithms is dynamic programming algorithms. We mention the paper of Roodbergen and Koster[27] on which a dynamic programming model is applied to routing order pickers. The paper also of Zhao et al [28] gives an dynamic algorithm for warehouse scheduling. On the paper of Muppani and Adil [29] a dynamic programming algorithm determines storage classes for the minimum storage space. Last but not least, a dynamic programming algorithm for computing tours in a warehouse is presented on the paper of Prantstetter and Raidl [30].

Solutions to warehouse layout problems also give few linear programming models. The papers of Kalinna and Lynn [31] on which a linear programming model is applied to Cube Per Index rule and the paper of Ballou [32] where a linear programming model is used for the improvement of physical layout are early studies in a warehouse layout problem.

Further to linear programming models, response to warehouse layout challenge gives the mixed integer programming. Worth to mention that these problem are characterized for its difficulty for problems with many input. Researchers try to bypass this difficulty with a variety of methods such as decomposition. As far as the literature concerns we find the model of Roodbergen and Koster [33] where routing methods, based on branch and bound method, for warehouses with multiple cross aisles are presented. Relative to previous paper is the paper of Gademann et al [34] on which a branch and bound algorithm is applied to ta wave picking in a parallel aisle warehouse. By the same method (branch and bound) Muppani and Adil [35] provide a solution to class storage location assignment problem.

Not only linear programming and mixed integer programming algorithms but also non linear programming algorithms have been applied to warehouse layout problems. This category of algorithms include papers such as the study of Zalman

[36] on which multiobjective programming is applied and the paper of Roodbergen and Vis [37] where a non linear programming model is developed for warehouse layout problem.

A popular type of algorithm for the warehouse layout problem is stochastic programming. It concerns models with stochastic and not deterministic variables and have as output probability distributions. In this category we find the models mentioned on the paper of Bhaskaran and Malmborg [38] on which tradeoffs are analyzed in relation to storage space. Next, the study of Du Lac and De Koster [39], where average throughput time of a random order is estimated. Similar to the previous paper on the paper of Malmborg [40] storage assignment policy tradeoffs are analyzed based on stochastic models. Further, Yu and De Koster [41] analyze the impact of order batching and picking area zoning on warehouse performance based on queuing network theory. Stochastic programming model is also used for the storage assignment problem on the paper of Pan and Wu [42]. Also Mainborg and Tassan [43] develop a stochastic model to capture impact of item , equipment ,storage configuration and operating parameters in less than unit load warehouse. Moreover, an analysis of optimal design of discrete order picking technologies is carried out by Eisenstein [44] using again stochastic model. Similar analysis is carried also by S. Li [45] developing a stochastic layout model. On the study average expected walk distance is calculated under various storage and path strategies. On the paper, also, of Nieuwenhuyse and De Koster [46] stochastic models are applied to calculate order throughput time in a 2-block warehouse. Last but not least on the study of Kapetanios et al [47] a stochastic model is applied to a cross docking warehouse operation with performance measures such as cycle time to be calculated.

Less popular type of algorithm than stochastic programming is simulated annealing algorithms. Two papers have dealt with warehouse layout problem and simulated annealing. The first is the study of Muppani and Adil [48], where storage classes formation is assessed by using simulated annealing algorithm. The other paper is this of Ho et al [26] on which neighborhood search and simulated annealing is combined in a two phase optimization process.

Interesting type of algorithm used for warehouse layout problems is particle swarm optimization. According to Onut et al. [49] “particle swarm is a stochastic optimization technique and also a population based search algorithm inspired by social behavior of bird flocking and fish schooling. Particle Swarm Optimization is a meta heuristic approach used for solving hard global optimization problems”. Papers and studies applying Particle Swarm Optimization technique to warehouse layout problem are:

- The study of Hsieh et al [50] which optimizes schedule order picking route in a distribution centre.

- The study of Kun et al. [51] on which an optimized bee colony algorithm is applied to warehouse layout of transit network.

- Particle swarm optimization applied to warehouse layout problem is also presented on the study of Chi et al [52]. The paper deals with the constrained warehouse layout problem.

- The study of Kaiyou and Yuhui [53] where constrained layout optimization using adaptive particle swarm optimizer is presented.

- Last but not least the paper of Onut et al [49] also presents a particle swarm optimization for the multiple –level warehouse layout design problem.

On the literature there are also general mathematical models solving warehouse layout problem. Some of them are

- The study of Malmborg and Bhaskaran [54], where optimal storage assignment policies are modelled and presented.

- The study of the above mentioned authors [7], where mathematically proves the optimality of cube per-order index rule.

- The paper of Roodbergen et al [55] on which optimal layout structure of manual order picking areas in warehouse is presented.
- The study of Goetschalcdx and Ratliff [56] computing optimal lane depths for single and multiple products in block stacking storage systems.
- The analysis of dual command operations in common warehouses carried out by Pohi et al [57], where a mathematical travel distance expression is developed.
- A general mathematical model is also developed by Pandit and Polekar [58] for the relationship between response time and optimal warehouse layout design.
- Order picking problem in narrow aisle warehouse is also mathematically modelled by Rana [59].
- The papers of Dukie ,Opetuk [60] and Pohi et al [61] deal with mathematical modelling for fishbone aisle warehouse layout.
- The paper of Malmborg [62] deals with an integrated storage system evaluation model. On the study an analytical base for cost components is developed.
- The paper of Geraldes et al [63] presents a mathematical warehouse design decision model.
- The last two papers of Elsayed, Unal [64] and Parikh and Meller [65] develop mathematical expressions for travel time in warehouse system.

The last type of solutions is algorithms found on literature that are not strictly characterized as mathematical or optimization. The paper of Mahonney and Ventura [66] is an example of other kind of algorithms since it introduces the dimensional analysis. In the same category is the paper of Buil and Piera [67] where a proposed methodology is presented for warehouse layout problems. The methodology is designed to meet all the supply chain constraints. Another methodology and its application to warehouse layout problems, this of Group Technology, is presented on the paper of Shaffer and Ernst [68]. Further, a process model and support tools based on a top down approach is provided by Bonder et al. [69]. A methodology, based on the theory of multi-attribute value functions, to allocate first choice and alternative warehouse space is provided on the study of Pliskin and Ron [70]. Moreover, on the study of Wilson [71] an iterative solution procedure is presented for warehouse space allocation problem. Further, Pohi et al [72] present a comparison of warehouse design problems for non traditional unit loads warehouse in effort to find out the optimum.

2.3 Simulation Models

As we mentioned at the beginning of our study there not only mathematical analytical models but also simulation models commonly used in warehouse layout problems since they are easier applicable. Main papers presenting simulation models are:

- The paper of Gray et al [73] on which a simulation model is applied to design and operation of an order consolidated warehouse.

- Simulation is also used for the comparison of picking , storage and routing policies in a manual order picking warehouse on the study Petersen and Aase [74].

- Similar to the abovementioned paper simulation method is used to configurate layout design in a manual order picking warehouse on the study of Garon et al. [75].

- Order picking warehouse design is evaluated also by simulation on the study of Huang and Cho [76].
- Order picking policies is also evaluated using simulation for mail order companies on the study of Peterssen [77].
- Improvement of order picking operation can also be achieved by using simulation according to the studies of Dukic and Olnic [78] and the study of Chan and Chan [79]. The last study refers to an increase in the productivity of order picking process.
- A simulation tool is also used to determine warehouse layout efficiencies and storage allocations on the paper of Macro and Salmi [80].
- Simulation is also used to model and evaluate AS/RS systems' operation on the paper of Muller [81].
- A useful application of simulation took place at the configuration of picking zone in order to achieve the minimum picker travel distances on the study of Petersen [82].
- Not only simulation models are used for picking operations but also for warehouse routing operations. On the paper of Bukard et al [83] a simulation model optimizes vehicle routing in an automated warehouse.
- Another application of simulation models concerns storaging. On the paper of Guenov and Raeside [84] zone shapes in class based storage are optimally evaluated by a simulation model.
- Similar to the abovementioned paper, performance evaluation of a warehouse system with one block class-based storage strategy is carried out using a Monte Carlo simulation model. The abovementioned analysis is presented on [85].

- Monte Carlo simulation is also used to solve the clean room space allocation on [86].
- Simulation methodology is also used for the configuration of new warehouse design at strategic and operational level on the paper of Buil and Piera [87].
- On the study of Gagliand et al [88] a simulation model is used for the total improvement of warehouse operations.
- The simulation model presented on the paper of Evensmo[89] deal with the warehouse layout.
- The paper of Malmborg and Bhaskaran [90] use simulation methodology to model the service process in a multi address warehousing system.

3 Conclusion and further research

On our study we categorize the warehouse layout problems according to the types and according to the solution algorithms. In the solution algorithms we further discern to analytical and simulation models. We propose for further research the categorization of simulation models according to simulation software used and the other types of metaheuristics used to solve warehouse layout problem.

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