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# A COMPREHENSIVE REVIEW AND CATEGORIZATION OF STOREHOUSE PROBLEMS

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## ABSTRACT

In this article an extensive review and categorization of storehouse problems is presented. The storehouse problems are viewed in a new way. This view classified the storehouse problems into three categories. These categories are order picking and routing methods for order pickers, order batching and batch construction, and product allocation and layout of order picking area. The first category is relevant to how the orders picking and routes are designed in the aim of minimizing the distance traveled to provide the customer's orders at the promised dates of ordered quantity. Second category is relevant to grouping orders into batches that are picked in a single tour and of a targeted objective of reducing the mean travel time per order. The third category is concerned with inventory management and storage location assignment in order to satisfy the customer's orders in an appropriate delivery date. The survey exhibits that the cited categories are tackled in different importance weights. The paper presents the main tools used as solver techniques for the considered categories.

في هذه المقالة تم استعراض مراجعة شاملة (مسح) لمشاكل المخازن و بناءا عليه تم تصنيفها. كما نوُقشت مشاكل المخازن على نحو جديد. وقد ُصنفت مشاكل المخازن إلى ثلاثة أصناف. هذه الأصناف هي التقاط الطلبية وطرق توجيه ملتقطي الطلبية، تجميع الطلبيات وبناء الدفعات، تخصيص أماكن المنتجات وتخطيط منطقة التقاط الطلبيات. التصنيف الأول يتعلق بكيفية التقاط الطلبات وطرق التوجه لالتقاطها والتي ُصممت لهدف تقليل المسافة المقطوعة لتزويد الزبون بالطلبات في التواريخ المحددة والكمية المطلوبة. التصنيف الثاني يتعلق بتجميع الطلبات في دفعات وبالتالي يتم التقاط كل دفعة في جولة واحدة بهدف تخفيض متوسط مدة الرحلة لكل طلب. التصنيف الثالث يهتم بتخصيص أماكن تخزين المنتجات وتخطيط منطقة التقاط الطلبيات لتحقيق طلبات الزبون وتسليم الطلبيات في وقت مرضي . تعرض المسح إلى معالجة الأصناف المذكورة بالنسبة إلى الأهمية المختلفة. عرضت الورقة الأدوات الرئيسية المستخدمة كتقنيات حلول للتصنيف المذكور.

***Keywords:*** Routing methods, Order picking, Order batching, Product allocation.

## 1. INTRODUCTION

The research on warehousing systems gained interest in 1970s. Warehouses form an important link in the supply chain. Products can be stored temporarily in warehouses and retrieving products from storage can fill customer orders. However, warehousing generally requires a considerable amount of product handling, which is time consuming. One way to decrease handling time is an entirely new design of the warehouse. But often it is also possible to decrease handling time by less radical methods such as changing the operational procedures [1].

The basic storehouse layout is one with parallel aisles, a central depot and two possibilities for changing aisles at both front and rear of the storehouse. In practice, many storehouses do not comply with this basic layout. Notably, in many storehouses it is possible not only to change aisles at the front and rear of the storehouse, but also at one or more positions in between called cross aisles.

In storehouses and distribution centers, products have to be picked from specified storage locations on the basis of customer orders. In general the order picking process is the most laborious of all storehouse processes. It may consume as much as most of all labor activities in the storehouse. One way to achieve savings on order pickers and equipment is by improving order routs. Given that, the order picker has to collect a number of products in specified quantities at definite locations, in what sequence should the order picker visit these locations in order to minimize the distance traveled?

In many storehouses the number of items per pick is less than that of a storage module such as a pallet. In particular if individual orders consist of relatively few items, efficient order picking can often only be achieved by grouping orders into batches. Then a batch of orders can be picked in one tour through the storehouse and the mean travel time per order will be reduced. The order-batching problem is the problem of distributing the orders among batches to enable efficient order picking policy, and of determining a batch picking tour for every batch [2].

There are several variants of this problem, depending on the environment where the orders have to be picked (e.g., manual, semi-automatic or automatic picking, the capacity of the pick vehicle) and the objective of order picking process. Sometimes sort-while-pick strategy can be applied, for example when all orders consist of relatively few small items. In that case an order picker can use a pick cart carrying a number of bins, such that items belonging to the same order can be disposed into the same bin. The advantage of this strategy is that no sorting is needed after the orders have been picked. But in some cases the pick-and-sort strategy needs to be applied, for example to use the storage capacity of a pick cart efficiently. Then all orders in a batch are disposed into one bin and the individual orders need to be sorted afterwards [2].

It is clearly observed from the brief introduction that there are different research prospective views for storehouse problems treatment. These different views have been collected and classified into three main categoryies as main research scopes correlated to storehouse management. These categories are considered in the following next paragraphs.

## 2. ORDER PICKING AND ROUTING METHODS FOR ORDER PICKERS

Order picking and material handling, in general, have received considerable attention since the 1970's. According to major researchers, order picking can be defined as the activity by which a small number of goods are extracted from a warehousing system, to satisfy a number of independent customer orders.

Order picking is the most critical operation in a warehouse. It involves the scheduling and releasing of customer orders, the picking of items from their storage locations and the disposal of the picked items. Order picking often consumes a large part of the total labor activities and accounts for a substantial percentage of the total operating cost in a warehouse. Therefore, the performance of the order picking system has large impact on the performance of a warehouse.

Nowadays, a critical topic in warehouse management practice is finding ways to answer the question 'How to increase order picking productivity and how to be more efficient?'

Bozer and White [3], presented an analytical design algorithm to determine the near minimum number of pickers required in an end-of-aisle order picking operation based on a miniload automated storage / retrieval system. Ratliff and Rosenthal [4], developed an efficient algorithm to find shortest order picking routes in rectangular storehouse that contains crossovers only at the ends of aisles. Roodbergen and De Koster [1], introduced several methods for routing order pickers in a storehouse with multiple cross aisles. Roodbergen and De Koster [5], presented an algorithm that can find shortest order picking tours in a parallel aisle storehouse, where order pickers can change aisles at the ends of every aisle and also at a cross aisle halfway along the aisles. De Koster and Van der Poort [6], studied the problem of findining efficient orderpicking routes for both conventional storehouse, where pickers have a centeral depot for picking up and depositing carts and pick lists, and modern storehouses, where order picking trucks can pik up and deposit pallets at the head of every aisle without returning to depot. Park et al. [7], studied an end-of-aisle order picking system with inbound and outbound buffer positions. The system is refered to as a miniload system with a horseshoe front-end configuration, and is modeled as a two-stage cyclic queueing system with limited capacity. They analyzed the system by utilizing known queueing results. Closed form expressions are developed for system performance measures, including the steady-state probability and system throughput. Bozer and White [8], addressed the design of end-of-aisle order picking systems by focusing on a miniload automated storage/retrieval system. Performance models are developed for the miniload and a design algorithm is presented.

Loon et al. [9], consider batching and storage allocation strategies in a manual order picking system of small parts, which processes high volume of orders. The order picking system is modeled by a two-stage queueing system with batching and picking activities. Yoon and Sharp [10], presented a numerical case study to illustrate a cognitive design procedure for an order pick system, which has been established through a series of interviews with and presentations to order pick system experts and literature review. Kolen et al. [11], described a branch and bound method that minimizes the total route length and presented some computational results in vehicle routing problems with time windows for a fixed fleet of vehicles of limited capacity available at a depot to serve a set of clients must be visited within a given time window. Solomon [12], considered the design and analysis of algorithms for vehicle routing and scheduling problems with time window constraints.

Daniels et al. [13], formulated a model for simultaneously determining the assignment and sequencing decisions, and compare it to previous models for order picking. The complexity of the order-picking problem is discussed, and an upper bound on the number of feasible assignments is established. Lin and Lu [14], proposed a computer based procedure that can determine appropriate order picking strategies in a distribution center. The mechanism of this procedure is two-phase. An analytic method is first employed to classify all orders into five categories. Computer simulation then follows to generate the appropriate picking strategies that correspond to each type of the orders classified. Jarvis and Mcdowell [15], provided a basis for locating an order picking storehouse such that average order picking time will be minimized. A stochastic model is developed to ensure that optimal, rather than just "good", results are obtained. Chew and Tang [16], presented a travel time model with general item location assignment in a rectangular storehouse system. They give the exact probability mass functions that characterize the tour of an order picker and derive the first and second moments associated with the tour. They apply the model to analyzing order batching and storage allocation strategies in an order picking system. The order picking system is modeled as a queuing model with customer batching. The effects of batching and size on the delay time are discussed with consideration to the picking and sorting times for each batch of orders. Kim et al. [17], considered an actual industrial storehouse order picking problem where goods are stored at multiple locations and the pick location of goods can be selected dynamically in near real time. They solved the problem using an intelligent agent-based model.

Van den Berg and Gademann [18], addressed the sequencing of requests in an automated storage/retrieval system with dedicted storage. They considered the block sequencing approach, where a set of storsge and retrieval requests is given beforehand and no new requests come in during operation. The objective for this static problem is to find a route of minimal total travel time in which all storage and retrieval requests may be performed.

Kim et al. [19], consederid an automated gantry-picking complex with 16 pick zones and 16 replenishment zones. New replenishment process logic for the gantry-picking complex was developed, to realize a short cycle time without loss of productivity. The main idea of the new replenishment logic is to minimize the set-up time. Experimental results demonstrating the efficiency of the new approach are also presented. Caron et al. [20], evaluated and compared the expected travel distance for different routing strategies namely traversal and return policies in low-level picker-to-part systems. Items are assigned to storage locations on the basis of the ratio of the required space to the order frequency (cube-per-order index (COI). For both routing policies, an efficient COI-based stock location assignment strategy is first developed. Second, analytical models are derived which relate the expected travel distance required to fill an order to the main system parameters (i.e the COI-based ABC curve; the number of picks in a tour; the number, length and width of aisles). Simulation results confirming the analytical models accuracy are presented.

In many cases, as some researchers have highlighted, the costs related to the order picking activity impact for more than a half of the total costs of a warehouse. The results of recent studies show that, by using appropriate combination of optimization methods, the picker travel distance can be reduced by about 60%.

As it has been exhibited from the comprehensive literature survey of the classified first category for the last three decades that most researchers focused on minimizing either the number of order pickers (picking strategies, batching and storage allocation and inventory deployment) or total travelling vehicle and times route distances (directly or indirectly by using cupe-per-order index COI). Most of the considered takled problems are of static nature of a single aisle or a very limmited number of parallel or multiple aisles and of limmited cross overs only at the end of aisle(s).

Little researchers have focused on the dynamicalty nature of storehouse operations. Modern storehouse structures have a little bit considerations where the trucks can pick up and deposit pallets at the head of each aisle without return to depot. The influence of moments associated with the tours of order pickers has also a little consideration of research interest. Also the system design profiles such as number of storage aisles, storage rack height and depth, vertical fleet size, number of lifts used and vertical movements are of little considerations.

Mathematical programming techniques are the most common methodology solvers used for solving the problem under consideration for first classification category. Also, a computer-based designed procedure based on performance measuring criteria, such as picking efficiency and accuracy, routes duration times, and system throughputs are of interest concern as solution methodologies for this category. Heuristics and intelligent agent-based methodology solvers are of little concern.

## 3. ORDER BATCHING AND BATCH CONSTRUCTION

It is often more effective for an order picker to retrieve items for many customers at the same time. This is called batch picking. When this method is used, we must separate the items belonging to each customer. Sorting systems are used for this purpose. The major types of sorting equipment are: conveyor, picking cart, sorting matrix (bin array).

Elsayed and Una,l [21], presented heuristics and analytical models for the order-batching problem. Orders are batched into tours such that the total travel time is minimized. Four heuristics are developed for the order-batching problem, for which no exact solution exists. All heuristics are based on the time saving criterion of combining two or more orders in a single tour rather than processing them one order at a time. Rosenwein [22], compared various heuristics for order batching. An important component of the study is comparing various metrics that approximate the relative "closeness" of a pair of orders and provide a quantifiable basis for assigning order to batches. Elsayed and lee [23], developed rules for sequencing and batching orders to tours such that the tardiness of retrievals per group of orders is minimized. Gademann et al [2], presented a branch and bound algorithm to solve order batching problems in parallel aisle warehouse with the objective to minimize the maximum lead time of any of the batches. Elsayed and Stern [24], presented algorithms for processing a set of orders in automated warehousing systems. The proposed algorithms will process the orders by grouping some of them according to criteria developed by the authors. The traveling salesman algorithm is then utilized to determine the optimal distance traveled within the warehouses for every group of orders. Ruben and Jacobs [25], developed and tested batch construction under three strategies for assigning storage space to individual items. The results indicate that, the methods used for constructing batches of orders and for assigning storage space to individual items can significantly impact order retrieval efforts in warehouses of this type. Pan and Liu [26], studied order batching algorithms composed of four seed selection rules and four order addition rules for order batching problems. They constituted 16 algorithms. In addition, another method, namely the (small and large) algorithm, is also considered. The performances of these algorithms are compared along the three dimensions of shape factor, capacity of storage and retrieval S/R machine, and storage assignment policy. Gibson and Sharp [27], used computer simulation to compare two new procedures for batching orders in an order retrieval system against a baseline procedure. The factros considered are the travel metric, storehouse representation, item location assignments, number of items per order, and the total number of orders considered.

De Koster et al. [28], investigated the orderbatching problem in storehouses. The batching and routing problems are complex to solve. In practice, simple methods are used for the batching problem, such as first-come-first-served (FCFS). Two groups of heuristic algorithms are evaluated: the Seed algorithms and the somewhat more complex (and CPU time consuming) Time Savings algorithms. The performance of the algorithms is evaluated using two different routing strategies: the so-called S-shape and Largest gap strategies, which are well known in theory and practice. The heuristics are compared for travel time, number of batches formed and also robustness. It is demonstrated that even simple order batching methods lead to significant improvement compared to FCFS. Seed algorithms are best in conjunction with S-shape and a large capacity of the pick device. Timesavings algorithms perform best in conjunction with Largest gap and small pickdevice capacity. If CPU time becomes imporant, then using simple Seed algorithms sould be considered.

Mendez and Henning [29], presented a new two-step systematic methodology for scheduling of single-stage multi-product batch plants. In the first phase, the product batching process is accomplished to minimize the work-in-process inventory while meeting the order's due dates. The set of batches so attained is then optimally scheduled to meet the product orders as close to their due dates as possible.

As it has been exhibited from the comprehensive literature survey of the classified second category for the last three decades that most researchers focused on constructing and grouping batches of orders (with or without storage space to individual items) such that the total traveling time is minimized or orders due dates are satisfied with zero delay or minimum lateness time. Some researchers consider the relative closeness of each pair of orders in grouping strategy and others have an interest concern in minimizing the maximum lead time between batches in case of parallel aisles. Others were interest in the performance of order batching algorithm and study their effect on shape factor, capacity of S/R machine and storage assignment dimension.

For this category, heuristic rules, analytical models and algorithms, and mathematical programming techniques are the most common solver tools used for this category. Computer simulation approaches and comparative metrics criteria are of a little concern.

## 4. PRODUCT ALLOCATION AND LAYOUT OF ORDER PICKING AREA

Usually the items in a storehouse exhibit varying characteristics with respect to dimensions, weight, demand, and other properties. It is natural to apply certain storage and retrieval strategies depending upon the product families or individual products within families. A basic rule in assigning products to storage locations is storing "better" products in the "better" locations in the order picking system. A "better location" is a location, which provides faster and more ergonomic access to the product stored.

A measure of "goodness" of an item could have been the frequency that it is requested. If an item is requested frequently, it is logical to keep that item in an easily accessible location. But if the item is too heavy, it may be too much time consuming to replenish that item to that favored location. Another measure of "goodness" for an item is occupying smaller space. On the other hand if an item is requested very infrequently, it is not necessary at all to assign it to a favored position, just because it occupies little space. If that practice were followed, the "best" locations could be filled with lots of small products that are not really requested much.

Another basic rule in assigning products to storage locations is taking into consideration the dimensions. Cube matching of the items with the storage locations is essential to eliminate space inefficiencies. Shelf dimensions should be spacious enough to allow easy picking, but tight enough to avoid unused space. Here is a bad usage of shelf space versus good usage.

Larson et al. [30], presented a procedure for storehouse layout. It employs the principles of class-based storage to increase floor space utilization and decrease material handling. Three phases of the procedure are outlined: (1) determination of aisle layout and storage zone dimensions, (2) assignment of material to a storage medium, and (3) allocation of floor space. Hariga and Jackson [31], developed a method of generating a cyclic schedule that minimizes the long-run average inventory and ordering costs per unit of time without violating a storehouse space capacity constraint. Pliskin and Dori [32], considered a choice problem among alternative space allocations. The choice is often made intuitively because of the difficulty in simultaneously considering multiple criteria (i.e, space categories), some of which are of conflicting nature. The paper employs the methodology of multi-attribute value functions to score and rank seven suggested area assignments. Bassan et al. [33], compared two configurations of shelves, in a homogeneous or a zoned storehouse. Handling costs as well as costs associated with the storehouse area and perimeters are taken into consideration. From these, expressions for optimal design parameters are developed. Park and Webster [34], presented a new storage structure layout method called "cubic-in-time", for minimizing the travel time of selected handling equipment in a three dimensional palletized storage system. Storage system design algorithms for minimizing travel times are described. Malmborg [35], presented a heuristic procedure for using the cube-per-order index rule to generate an initial item assignment followed by an improvement step. The improvement step is based on a re-partitioning of the item population among storage aisles to generate improvements in expected order picking cost. Caron et al. [36], presented an analytical approach to layout design of the picking area in low-level, picker-to-part systems using (cube-per-order index) based and random storage policies. Berg and Gademann [37], presented a simulation study of an automated storage/retrieval system (AS/RS) and examined various elements of AS/RS control: storage location assignment policies, request selection rules, open location selection rules and urgency rules.

Bozer and White [38], developed travel-time models for automated storage/retrieval (AS/R) machines. The (S/R) machine travels simultaneously horizontally and vertically as it moves along a storage aisle. For randomized storage conditions expected travel times are determined for both single and dual command cycles. Johnson [39], developed an analytical model of an order sortation system used in automated distribution centers. In such systems, groups of orders are delivered to a recirculating conveyor system where they are stored into shipping lanes for final preparation and loaded onto waiting trucks. They developed a model of the sorting process, which incorporates the stochastic elements of these systems, to determine the relative merits of two common categories of sorting strategies found in industry: fixed priority schemes and the next available rule. Brynzer and Johansson [40], concerned the stock location assignment problem (SLAP) and described a strategy for pre-structuring components and information for picking work in storehouses. This classification is derived from the product structures transformed to support a holistic perception aimed at the material handler/picker.

Meller [41], considered a two-level order accumulation/sortation system and developed an algorithm to optimally assign orders to lanes based on the arrival sequence of items to the sortation system. With the use of the algorithm they showed significant throughput increases, where throuhput is based on the time to sort a complete order pick-wave. Rosenblatt and Eynan [42], determined the optimal boundaries for class-based AS/RS systems. A solution procedure is developed which requires only a one-dimensional search procedure. It is shown that most of the potential improvement in the expected one-way travel time can be obtained when the storehouse is divided into a relatively small number of regions.

Guenov and Raeside [43], investigated the effect of zone shape in a class based storage on the optimal picking tour of S/R machine. The expected value of S/R machine travel time for multi command order picking is derived as a function of number of addresses and rack area. This used to model the two zones of fast moving products in a three-class storage system. Each of the three investigated configurations was tested by computer simulation in a full factorial experiment. The results are presented and indicate that the proposed configurations perform well and could be used in practice. Van Oudheusden and Zhu [44], presented a straightforward methodology to design the storage layout of a rack when such recurrent orders represent a high percentage of total turnover. The approach makes use of sorting, assignment, and travelling salesman like algorithms. The resulting layouts are compared against more classical arrangements. Numerical simulations show that, in specific situations, more than 30% saving in travel time of the retrieval crane can be expected. Vaughan and Petersen [45], investigated the effects of adding cross aisles to the layout of an order consolidation storehouse, with respect to order picking efficiency. A shortest path pick sequencing model is devolped, which allows for any number of cross asiles in the storehouse. The optimal routing is computed for a large number of randomly generated picking requests, over a variety of storehouse layout and order picking parameters. The results are used to characterize the optimal number of storehouse cross aisles, as well as the conditions under which cross aisles generate the greatest benefit. Zhang et al. [46], investigated a new kind of storehouse layout problem, multi-level storehouse layout problem (MLWLP). Both horizontal and vertical travel costs need to be considered when making a layout. In the problem, unit travel costs are item dependent and different items can be mixed in a cell. An IP model is proposed, which is shown to be NP-hard. An effective assignment method is presented and genetic algorithm heuristics developed. Extensive computational experiments are conducted to verify the effectiveness of the algorithms.

Ashayeri et al. [47], presented an exact, geometry-based analytical model used to compute the expected cycle time for a storage/retrieval (S/R) machine, executing single-commands, dual-commands, or both, in a rack structure that has been laid out in pre-specified storage zones for classes of goods. The model can be used by designers as a tool for quickly evaluating alternative layout configurations with respect to expected S/R cycle time in an AS/RS, and thereby the throughput of an automated storehouse over time. Park [48], developed an optimal dwell point policy for automated storage/ retrieval systems with uniformly distributed racks. For non-square-in-time racks, he presented the closed form solution for the optimal dwell point in terms of the probability of the next transaction demand type: storage or retrieval. He also introduced various return paths to the dwell point for the efficient operation of the storage/retrieval machine.

Malmborg [49], modified a well-known rule of thumb for evaluating storage rack configurations in automated storage and retrieval (ASR) systems to avoid the need for two key assumptions. These are the proportion of single and dual command order picking cycles used in operating a system and the total storage capacity requirements when randomized versus dedicated storage is used. Procedures for generating ASR system cost estimates are also directly coupled with models for estimating the utilization of storage and retrieval machines. Additional performance criteria for evaluation of alternative rack configurations are proposed. The modified rules of thumb are also designed for implementation on PC-level hardware, but with adequate computational efficiency for analysing a broad range of rack design alternatives in large-scale applications.

Yang [50], proposed heuristic allocates shelf space item by item according to a descending order of sales profit for each item per display area or length. Through the use of simulations, the performances of objective value and the computational efficiency of this method are evaluated. Three options are also proposed for improving the heuristics. Compared to an optimal method, the improved heuristic is shown to be a very efficient algorithm, which allocates shelf space at near-optimal levels.

Sagan and Bishir [51], developed an algorithm for maximizing the solution of a non-homogeneous linear partial difference equation of second order with homogeneous boundary conditions, for two versions of a product are to be stored in a facility of given capacity. The (complementary) probabilities with the two demand products are known. It will be demonstrated how storage space is to be allocated to make the supply (of both versions) last through a maximum number of consecutive orders by the developed algorithm. It will develop that for small storage facilities; the ratio of the optimal numbers of assigned storage spaces for the two versions can deviate considerably from the ratio of the corresponding demand probabilities. However, this ratio will approach the ratio of demand probabilities as the number of available storage spaces tends to infinity.

Multi-shuttle automated storage/retrieval systems have been developed for use in factories and distribution centers because they are more efficient than single-shuttle systems (owing to less empty travel). This improved efficiency results in more agile support (flexible response, less waiting time, etc.) for the production system the storage/retrieval system serves. Meller and Mungwattana [52], developed analytical models to estimate the throughput in multi-shuttle systems. Throughput improvements greater than 100% are illustrated when triple-shuttle systems are compared with single-shuttle systems.

Chen et al. [53], considered two allocation problems namely, allocation of bandwidth and storage. In these problems, they faced a number of independent requests, respectively, for reservation of bandwidth of a communication channel of fixed capacity and for storage of items into a space of fixed size. In both problems, a request is characterized by: (i) its required period of allocation; (ii) its required bandwidth; and (iii) the profit of accepting the request. The problem is to decide which requests to accept so as to maximize the total profit. These problems in general are NP-hard. They provided polynomial-time algorithms for solving various special cases, and developed polynomial-time approximation algorithms for very general NP-hard cases with good performance guarantees.

Park [54], developed an optimal dwell point policy for automated storage/retrieval systems. Also, determined the optimal dwell points in closed form for square-in-time racks with dedicated storage. And confirmed the intuitive result that the input point is a good alternative dwell point for dedicated storage.

Koh et al. [55], studied the characteristics of a warehousing system in which the storage and retrieval orders are performed by a tower crane. The crane is located at the center of the round storage area and it can rotate in both clockwise and counterclockwise directions. They developed some mathematical travel time models for this warehousing system using the characteristic of S/R crane that is device can move in radial and circumferential directions simultaneously. Wu and Appleton [56], presented a method to solve the layout and aisle structure problems simultaneously by a slicing floorplan. In this representation, the slicing lines are utilised as the aisles for a material handling system. The method decomposes the problem into two stages. The first stage minimises the material handling cost with aisle distance, and the second stage optimises the aisles in the aisle structure.

Malmborg [57], proposed a simulation based sampling procedure for estimation of collective item space requirements when random storage policies are used in warehousing systems. The procedure is based on defining space requirements distributions associated with individual items and then using a Monte Carlo sampling procedure to generate the probability distribution of space requirements for different items co-located in the same group of physical storage positions. A sample problem is used to illustrate the application of the procedure in the early phases of automated storage and retrieval system design.

Marvel et al. [58], developed heuristic algorithms that integrated human storehouse expertise and a computerized system to aid a selecting highly efficient storage locations in a food distribution storehouse utilizing pallet jack order picking vehicles and a single traversal order picking policy. Examining and quantifying the current decision logic that determined item location within the storehouse was the basis for designing the heuristic rules. In a limited simulation study, the layouts generated by the algorithms decreased total picking time and traveling distance by more than 10% and 20% respectively compared to a random assignment layout.

Gopalakrishnan et al. [59], presented a heuristic method for assigning products to storage locations in third party storehouses that, in addition to providing storage, also provide assembly and kitting operations. This method is demonstrated via a case study and an associated computational system that supports the analyst in storage location planning. Ventura et al. [60], investigate the application of Group Technology to storehouse layout design in the healthcare industry. A cost model for a hospital storehouse has been developed to minimize annual operations cost based on the optimal grouping of medical supply items as used by nursing stations. The cost function includes two components, a cost associated with the storehouse area and a transportation cost related to retrieving items from the storehouse.

Malmborg [61], proposed analytical conceptualizing tools based on the features of autonomous vehicle system for modelling expected performance as a function of key system attributes including storage capacity, rack configuration and fleet size. The models are demonstrated for a sample problem and compared with analytical conceptualizing tools used for automated storage and retrieval systems. Barbucha [62], presented three approximation algorithms for solving the generalized segregated storage problem (GSSP). GSSP involves determining an optimal distribution of goods among a set of storage compartments with the segregation (physical separation) restrictions. GSSP is a new generalization of well-known segregated storage problem. The paper gives problem formulation and proposes three approximation algorithms for solving it: a specialized construction heuristic and two population-based algorithms, an evolutionary algorithm, and population-learning algorithm. The algorithms are evaluated in computational experiments. The analysis of variance method was used for statistical analysis of obtained results.

De Koster et al. [63], give a literature overview on typical decision problems in design and control of manual order-picking processes. They focus on optimal (internal) layout design, storage assignment methods, routing methods, order batching and zoning. Combinations of the above areas have hardly been explored. Muppani et al. [64], proposed a nonlinear integer programming model to capture the effects of storage area reduction on order picking and storage space cost are incorporated. A branch and bound algorithm is developed to solve the model. Computational experience with randomly generated data sets and an industrial case shows that branch and bound algorithm is computationally more efficient than a baseline dynamic programming algorithm. Yu and De Koster [65], proposed an approximation model based on queuing network theory to analyze the impact of order batching and picking area zoning on the mean order throughput time in a pick-and-pass order picking system. The model includes the sorting process needed to sort the batch again by order. Results from a real application and simulation show that this approximation model provides acceptable accuracy for practical purposes.

As it has been exhibited from the comprehensive literature survey of the classified third category for the last three decades that most researchers focused on studying the effect of different layout designs and configurations in the aim of increasing floor space utilization and decreasing traveling time, (horizontal or vertical) of material handling, and costs. The researchers handled different varieties of layout design configurations and material handling equipment such as: class-based storage of a space capacity constraint, zone shape structure, shelves configurations, line level layout, single or parallel aisles with or without cross aisles, storage rack configurations in automated and retrieval systems (ASR), multi-shuttle system, layout configurations with aisle structure and slicing floor plane, one way travel structure with small regions of layout design, rack storage layout design with high percentage turnover, layout configurations and S/R cycle time in an AS/RS and their throughputs, material handling equipment of constrained palletized storage system, and storehouse characteristics when storage and retrieval orders are performed by a tower crane.

Also, some researchers have an interest on either storage and/or retrieval in either automated or non-automated system and the influences of the proposed strategies on the system measuring performance criteria such as: traveling time for both single and dual command cycles for randomized storage in automated storage/retrieval (AS/R) machines, storage policy with travel time and storage space in case of balanced input and output and sequence in time rack with dedicated storage, closed form solution for optimal dwell point for AS/RS and of uniformly distributed racks, and minimize the maximum response time to service incoming requests in AS/RS.

Some other topics are studied in this category such as: effect of group technology to storehouse layout design, pre-structuring components and information for picking orders, generating initial items assignment among storage aisles to improve order picking cost, and many different analytical models used for order sortation.

For this category heuristics and heuristic rules and procedures, analytical models and algorithms, dwell point policies, simulation approaches and mathematical programming are the most common solver tools for the considered category. Genetic algorithm is used as a solver methodology for this category.

With thousands of items being stored and retrieved in a system, it is crucial to maintain control and track the movement of items. Barcodes are an important technology for identification of items when they are received, stored, retrieved, assembled into orders, and shipped. Typical planning issues in storehouses are inventory management and storage location assignment. Intelligent inventory management may result in a reduction of the warehousing costs. For example, by applying sophisticated production planning and ordering policies we may reduce the total inventory, while guaranteeing a satisfactory service level. The service level specifies the percentage of the orders to be supplied directly from stock. Reduced inventory levels not only reduce inventory costs, but also improve the efficiency of the order-picking operation within the storehouse. Clearly, in a smaller storehouse, the travel times for order picking are smaller.

Furthermore, an effective storage location assignment policy may reduce the mean travel times for storage/retrieval and order picking. Also, by distributing the activities evenly over the storehouse subsystems, congestion may be reduced and activities may be balanced better among subsystems, thus increasing the throughput capacity.

## 5. CONCLUSION

In this paper we address a comprehensive survey and classification scheme of storehouse systems. The storehouse problems are viewed in three categories; layout design and product allocation, batch construction and order batching, and order picking and routing. Also, storehouse management is discussed. The survey exhibits that layout design and product allocation problems are of great interest of researchers while batching construction and order batching of least concern. No layout design configurations can be used as a best design for all storehouse problem configurations. And also no strategy can be used as a best methodology or policy for the problem under consideration. The dynamically nature is of a little concern of storehouse operations and hence it is recommended to consider it as a reality issue for future work. Modern storehouse structures and the moments associated with the tours of order pickers are recommended as reality features for the future researches to improve the performances of the suggested methodology of the considered layout design. Heuristics, heuristic rules and intelligent aids are more powerful tools in solving problem categories and hence it is recommended to use hybrid intelligent procedures as efficient solver tools for problem under consideration.

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