A comprehensive review of warehouse operational issues

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A Comprehensive Review of Warehouse Operational Issues

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Abstract

This paper comprehensively discusses the existing state-of-the-art warehousing literature and highlights concerned research issues as per the proposed taxonomy. All previous reviews broadly focus on warehouse design and operational issues ignoring performance measures affecting each function of warehousing and overall productivity. Therefore, this paper tries to identify the specific performance measures and methods, and explore their impact on the overall logistics system. Each individual section has been concluded with important findings and these are summarised along with converged research guidelines in the last section. The proposed gaps would provide a future road map for research in existing and other unexplored directions in warehouse operations and management.

Keywords
Warehouse management, Performance measures, Automated warehousing system, Productivity, Materials handling equipment, Lean warehouse design

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1. Introduction

The objective of a warehouse is to satisfy customers with effective resource utilisation and delivering the right product, at the right place and at the right time in good condition (Frazelle, 2002a). According to Heragu et al. (2005), warehouse is a means of providing functions of temporary storage, protection of goods, fulfillment of individual customer orders, packaging of goods, after sales services, repairs, testing, inspection, Just in Time (JIT) sequencing and assembly. Major warehouse operations are classified into receiving, picking, storage and shipping (Gu et al. 2007). The storing function includes various sub functions like department or locations assignment and zoning. Further, the batching, routing and sorting have been considered as part of the picking process. Rouwenhorst et al. (2000) presented a framework to classify these operational decisions with respect to organizational levels (e.g. strategic, tactical and operational) and resources (e.g. man, machine, storage and handling equipment). Different researchers have shared their views on operational issues and decisions classifications (Tompkins and Smith, 1988; Frazelle, 2002b; Heragu et al. 2005; De Koster et al. 2007; Gu et al. 2007; Pohl et al.2011). They found out that all the operational issues are interrelated and mutually affect the performance of one another. De Koster et al. (2007) have reviewed picking decisions such as layout, storage assignment, routing and batching from design and control perspective. They have thoroughly studied existing literature and presented future gaps in the picking taxonomy. On this basis, we present a general framework (Figure 1) showing warehouse operations with basic activities, different process flows and equipment used at different stages.. The review process followed is discussed below along with the framework and derived taxonomy.

2. Literature review

A structured review of literature is an attempt to study warehouse operational issues and affected performance measures including quality journals, handbooks, bulletins, doctoral theses, conference reports and other online resources. Several peer-reviewed articles are explored through keywords like Warehouse design, Warehouse operations, Warehouse management, Materials handling devices (e.g. routing, batching, picking, storage etc), Optimisation, Automated warehouse systems and Lean warehousing. A critical review was conducted after collecting articles from online databases like Inderscience, Science Direct, Taylor and Francis, Emerald, Springer, and IEEE. The objective was to thoroughly review the existing literature with a perspective to understand how different warehouse operations are related and can be improved upon.. Accordingly, the classification of operational issues is derived and revised again by re-searching the papers. As an outcome of the framework followed as shown in Figure 2, the review is recorded in the form of this paper and the taxonomy is defined. The proposed taxonomy has been designed on the basis of the warehouse distribution handbook (Rushton et al. 2006) and modified accordingly. Each operation of the warehouse is classified into picking, routing, handling equipment, sorting, layout, replenishment and productivity. The picking concepts and equipment are further classified for better readability as shown in Figure 3.

Gu et al. (2007; 2010) reviewed design research issues such as overall structure (e.g. layout, dimensioning, sizing etc.), operational strategy (e.g. storage-picking) and performance evaluation models and classified them as benchmarking, analytical models, computational models and case studies. De Koster et al. (2007) conducted a review for design and control of picking operation. Routroy and Kodali (2008) presented a strategic level decision framework in order to determine optimal number of warehouses and their required capacity in supply chain network. Roodbergen and Vis (2009) classified Automated Storage and Retrieval Systems (AS/RS) and provided a thorough literature review for overall warehouse operations considering design level performance measures. Baker and Canessa (2009) addressed design procedures followed in different companies along with different tools and techniques. Further, proper co-design of the production and logistics systems can result in significant cost savings (Dai and Tseng, 2011). Also, several studies found optimising cost with different design contexts like warehouse location, vehicle routing and legal taxes respectively (Prasad and Shankar, 2011; Nidhi and Anil, 2011; Mathirajan et al. 2011). A two-warehouse inventory model with First in, First out (FIFO) and Last in, First out (LIFO) dispatching policies has been proposed considering partial backlogging rate in order to optimise inventory costs (Jaggi et al. 2013). Gagliardi et al. (2012) studied performance models for AS/RS and classified them accordingly. Davarzani and Norrma (2015) conducted comprehensive review on warehousing and suggested gaps for future research. They also interviewed practitioners providing realistic insights to confirm the outcomes of the review process. Staudt et al. (2015) presented a review on performance measures for warehouse operations. More recently, Shah and Khanzode (in-press) reviewed warehouse storage-handling systems from lean perspective and presented a framework for it.

All previous reviews broadly focus on warehouse design and operational issues ignoring performance measures affecting each function of warehousing and its overall productivity. This paper addresses the gap, tries to identify the performance measures, methods and explore their impact on the overall logistics system. It also provides a fresh perspective on the existing state-of-the-art literature along with performance measures, their impact and general guidelines for future research. The following section presents an in-depth discussion on existing literature and highlights the concerned research issues as per the proposed taxonomy. Section 3 discusses some important contributions and findings of literature review along with their limitations. Finally, the last section summarises the managerial implications and converged research guidelines for future research.

2.1 Picking concepts

Different authors define order picking process differently, although with almost the same meaning as follows. In order to satisfy a customer order in low-level picker-to-part system, where the picker performs retrieval of items from storage locations as per prescribed order is called 'picking' (Hwang and Kim, 2005). As per the definition given by Le-Duc and De Koster (2005), this is the process of retrieving required items from their storage locations in order to fulfill a number of independent customer orders. According to Rushton et al. (2006), picking represents key objective of warehouse, and they defined it as 'the process to extract the particular goods from inventory required by customers and bring them together to form a single shipment--accurately, on time and in good condition'. Dukic and Oluic (2007) tried various combinations of picking methods using simulation and demonstrated significant reduction in distances travelled. Pan and Shih (2008) defined order picking as 'the warehouse process initiated in order to accomplish customer order at correct time in correct quantity'.

The picking activity is the most important operation in achieving efficient warehouse (Burinskiene, 2010) functioning. Its importance in terms of cost, time and labour productivity is acknowledged by the researchers over a period of time and discussed widely in literature as stated here. According to Coyle et al. (1996), around 50–75% of the total operational costs of a warehouse are attributed to picking operations. Out of the overall operational costs of warehouse a vital portion is consumed by the order picking and allied functions (Tompkins et al. 2003). Talking from the cost perspective, the picking accounts for roughly 55% of the total operational costs. Heragu (1997) analysed warehouse operations and stated that the order picking is the single largest expense in warehouse operations. This order-picking function comprises of 65% of the total operational costs for a typical warehouse (Drury 1988). Bartholdi and Hackman (2006) have divided the overall order picking time into a number of sub processes as follows: travelling -55%, searching-15%, extracting-10%, paperwork and other activities -20%. Ruben and Jacobs (1999); Gademann and Van De Velde (2005) viewed it from the labour utilisation perspective and have stated that in general the picking process consumes about 60% of all labour activities in the warehouse. Order picking accounts for about 50% of the direct labour costs of a warehouse (Rushton et al. 2006). In one of the most cited articles in this field, Frazelle (2002a) claimed that the order picking has been identified as the most expensive warehouse and supply chain operation (labour intensive for manual warehouse and cost intensive for automatic warehouse). It constitutes around 55% of the overall expenses. In support of this other researchers claimed that picking may constitute as much as 60% of all labour activities and may account for as much as 65% of all operating expenses (Won and Olafsson, 2005; Ashayeri and Goetschalckx 1989, Bachers et al. 1988; Bukchin et al. 2012).

The existing literature adequately answers the question: 'why order picking function has received more research interest at operational level?' We summarise that picking is a major driver affecting performance at operational level. Although all functions and related activities or sub activities are tightly coupled (Rouwenhorst et al. 2000), we have tried to separate out and discuss them individually. The following section explains different picking policies and operational considerations. In their review paper, Gu et al. (2010) discussed and identified three types of picking policies i.e. zone, wave and batch picking as explained below:

2.1.1 Zone picking

The storage space is divided into picking zones and each zone has one or more assigned pickers who only pick in their respective assigned zone. Zoning is defined as a logical storage area which may include pallet storage area or entire warehouse is split into multiple sections, each with different pickers (Rushton et al. 2006). The zones can be determined or formed on the basis of product size, weight, temperature and safety requirements. This approach is applicable where individual orders are beyond the capacity of one picker to collect in one circuit, and where the reasons for meeting dispatch deadlines, it is not feasible to pick sequentially until an order is complete. This has several advantages, for example a particular assigned picker has to travel less distance because of familiarity; quick and responsive picking can be achieved; the pickers' routes are limited to dedicated respective zones resulting in reducing delay and congestion. On the other hand, there is a shortcoming too, as all orders require consolidation before final shipping which consumes more time, cost and efforts (De Koster et al. 2007). This shortcoming can be overcome by sequential and parallel zone picking.

2.1.1.1 Sequential zoning

In sequential zone picking the containers can hold one or more orders that are passed sequentially through the zones. It is also referred to as progressive picking (De Koster et al. 2007) as an order can be completed only after visiting all relevant zones. Bartholdi et al. (1999; 2001) proposed a new bucket brigade method similar to sequential zoning with fixed zone sizes and relaxed the pickers from zone restrictions. It is more dynamic in terms of zone sizing and assigning pickers (De Koster et al. 2007). The advantage of such a system is that it is efficient and self-balancing with respect to workload. This policy is also referred as 'pick-and-pass' wherein, a receptacle is continuously passed from one zone to another and a picker picks the items required for an order from that zone and then passes it on to the next zone (Rushton et al. 2006). Pan and Wu (2009) proposed an analytical model to estimate travel distance using Markov chain in the 'pick-and-pass' system. They have tested the optimal storage assignment model for single picking zone with a single picker and with equal-unequal sized model with multi-pickers as well. The congestion and optimal travel starting position is expected to be considered in future.

2.1.1.2 Parallel zoning

While in parallel or synchronised picking, the number of pickers start in the same order simultaneously in their own zone and later on merge the order. Many such processes identified as both sequential and progressive zoning can also be considered with or without batching (Gu et al. 2010). Some of the other concepts improving picking are 'pick-to-order' (De Koster et al. 2007) and 'pick-by-line' in case of cross-docking (Rushton et al. 2006) respectively. De Koster (1994) estimated throughput times and average work-in-process of an order using a Jackson queuing network-based simulation in a zoned pick-and-pass system. The results are used to determine the number of zones and the system size. Petersen (2000) investigates the factors affecting travel distance within zones using simulation and found out that factors such as the number of aisles per zone, aisle length, and number of items on the picking list and storage policy also have a role in this system. Malmborg (1995) studied zoning with constraints to solve product assignment problem. In order to resolve such issues, Jane (2000) proposed, heuristic algorithms for a progressive zoning system and advised to adjust the zone size for order volume fluctuation. Jane and Laih (2005) assigned products to zones in a synchronised system where the items of the same order are stored in the same zones. Le-Duc and De Koster (2005) have determined optimal number of zones in a synchronized zoning system using mixed-integer linear programming in order to minimise the total order-picking and assembly time. Some studies are found on zoning in combination with batching as Mellema and Smith (1988) examine the effects of the aisle configuration, batching, stocking policy and zoning rules using simulation. They have suggested that a combination of batching and zoning can significantly increase the productivity (pieces per man-hour). Gray et al. (1992) propose a hierarchical framework for warehouse designing with zone picking in order to determine the number of zones and pickers, zone size, batch size, and zone shape. Choe et al. (1993) proposed an analytical tool for planning and evaluating various strategies such as single-order-pick, sort-while-pick and pick-and-sort within aisle-based warehouse. Petersen (2000) compares and simulates different order-picking policies (e.g. single order picking, batch picking, sequential zone picking, concurrent zone picking, and wave picking) with the number of orders and skewed demand as control variables, and warehouse layout, storage assignment and zone configuration as fixed variables. But they have only considered performance measures related to order picking efficiencies and service quality while additional costs caused by downstream sorting have been ignored. Additional costs in the form of sorting in parallel zoning and queuing in sequential picking may be incurred in zone picking, which needs to be addressed. The effect of zone size on operational costs has been investigated by Petersen (2002), which concludes that zone and batch sizes have a significant impact on operational costs. Jewkes et al. (2004) solve the problem of assignment, zone sizing and picker home base location for a progressive system using dynamic programming in order to optimise the picking cost.

2.1.2 Wave picking

It is a strategy wherein the orders are picked up in waves with similar (same pick date, time, carrier or same transport medium) subsets of orders that are required to be shipped together. They should also be completed during the same time period to avoid intermediate storage, staging and restocking. This timing is determined by the outgoing vehicle schedule or by the time requested by the customer. Gademann et al. (2001) tried to minimise maximum lead-time of any batch in manual wave picking algorithm. Taljanovic and Salihbegovic (2009) proposed a wave planning approach focusing on continuous throughput and material flow improvement across all warehouse operations. Again the same researchers (Taljanovic et al. 2011) extended wave picking system and tried to improve picking operations with the aid of pick-and-pass approach. The authors solve the problem of small, non-serialised jewellry parts where multiple orders can be picked up simultaneously without sorting in order to reduce cost and time. The authors have further identified the application of artificial intelligence (AI) and software agents overriding the intelligence of the human labour force for future research.

2.1.3 Batch picking

It involves the assignment of a group of orders to a picker which are to be picked simultaneously in one trip. Order batching is a means of reducing waiting time for customers, holding time in system, travel time for pickers and increasing overall throughput of the picking system (Hwang and Kim, 2005). Won and Olafsson (2005) have summarised that intelligent batching results in improved time and resource utilisation. Roodbergen and Vis (2006) defined batching as a process of combining more than one customer order in one or more picking routes or trips. Elsayed and Stern (1983) have tested 24 batching algorithms using simulation. Rosenwein (1996) conducted a simulation study using batching in conventional warehouse in order to analyse maximum throughput. Choe and Sharp (1991) categorised batching on the basis of proximity of picking locations and time windows. Gademann and Van de Velde (2005) presented a branch-and-price algorithm for order batching problem and found that the batching problem is treated as NP hard when the order size is more than two. For larger instances they proposed iterated descent approximation algorithm. Chen and Wu (2005) measured proximity among orders on the basis of association and prsented a clustering model to maximise associated batches. Later on, Chen et al. (2005) and Hesu et al. (2005) presented data-mining and genetic algorithms respectively in order to improve such problems. Haq and Kannan (2006) presented an inventory model on the basis of genetic algorithm in order to optimise inventory of two-echelon bread makers' supply chain.

De Koster et al. (2007) have referred to batching as 'pick-by-article' where multiple orders of different customers for same type of items are grouped or batched and picked simultaneously by an order picker. Whereas Henn and Wäscher (2012) define order batching as combining customer orders to make maximum capacity utilisation of the picking cart. It is applicable for small orders where picking only one order per circuit is not economical. After completion of retrieval of a batch (many orders) and order processing, sorting is required to de-assemble individual customer orders for shipment called, 'sort-after-pick' approach. In such a strategy, order splitting is possible, so it is required to sort items after picking. Tang and Chew (1997), Chew and Tang (1999) and Le-Duc and De Koster (2003, 2007) have presented a batch service model in order to determine optimal batch size considering stochastic order arrival pattern with variable time window order batching and fixed number of items per batch. They have simulated the model and concluded that this approach provides a high accuracy level. According to Hwang and Kim (2005), this process become costly and consumes more time as the number of customers or orders increases. This shortcoming can be overcome by joint approach of batching and picking wherein the picker sorted out order wise products in different bins or container while picking only is referred as, 'sort-while-pick' method. Gibson and Sharp (1991) analyses some batching procedures for 'batch-while-pick' method and proposed new batching processes with simulation validation. Petersen and Aase (2004) have conducted a simulation based study with different storage, picking and batching policies and found batching has the largest impact on reducing overall order fulfillment time. As discussed earlier. Hwang and Kim (2005) conducteda study combining routing and batching while assuming picking locations and routing strategy are known in advance. In their review paper De Koster et al. (2007) found much research work by Ruben and Jacobs (1999) and De Koster et al. (1999) for single and multiple aisle systems using seed algorithm.

Elsayed and Unal (1989) proposed heuristics for batch assignment in order to reduce travel distances. Petersen (2000) determined the batch size and found that it depends on picking time. Bozer and Kile (2008) studied 'walk-and-pick' strategy, proposed heuristics algorithm that provides solutions with the least walk times require substantial computational time for large waves. Similar research has been also conducted by several researchers (Gibson and Sharp, 1992; De Koster et al. 1999; Ruben and Jacobs, 1999) in order to reduce travel time by assuming finite capacity of the picker. They also assumed order integrity constraint and ignored congestion due to multiple pickers in the same area, which in future will be required of being relaxed. Moreover, further study is required to reduce computational time and to improve throughput by determining ideal batch size. Pan and Shih (2008) had addressed the issue of throughput and congestion in multi picker environment. They have focused on tradeoff between picking distance and storage delay using tandem queue networks with finite buffer (Refer Takahashi et al. 1980). Finally, they summarise that random storage gives highest throughput with high demand distribution and less congestion. The basic objective of batching should be to minimise lead time or to improve response time. Elsayed et al. (1993) and Elsayed and Lee (1996) proposed heuristics to form batches and determine release time for them. Here, order due dates, penalties, earliness and tardiness are considered as objectives of their study. In modern Warehouse Management System (WMS), the routing heuristics are not useful for systematic picking operation. Therefore, some optimisation is required for efficient batching and storage (Moeller, 2011). They used Line Sequence Optimisation (LSO) to calculate the line sequence for a given batch for optimal travel time at the electronic devices distributor warehouse.

Won and Olafsson (2005) have focused on customer response time and picking efficiency through combined consideration of batching and picking operations respectively. Tsai et al. (2008) proposed batch picking optimisation model considering travel cost, tardiness and earliness penalty. There are a number of constraints they have assumed, which are not really accepted in real world such as dedicated storage with identical size, divisible orders, batch size is less than picking capacity and stock-out was ignored. The multi GA was used to optimise picking batch in form of GA_BATCH and GA_TSP. When the new order arrives, either the picker starts picking or waits for more orders to form a batch for efficient picking in order to save time, energy, efforts, capacity utilisation and finally cost. On the other hand, if a picker has to wait, then such a situation not only leads to increased penalty in the form of tardiness but also affects the overtime cost and worker utilisation issues which need to be addressed. Bukchin et al. (2012) focused this tradeoff between immediate picking and wait till the order can be processed in the defined deadline. They tried to reduce tardiness times and overtime picking costs in dynamic picking process to check the effect of these two proposed situations using Markov Decision Process (MDP) based heuristics. The order arrival rate here is assumed to be following poisson distribution which needs to be relaxed in future. The stochastic simulation has been suggested as further study. Henn and Wäscher (2012) studied distribution center and proposed meta-heuristics based on Tabu Search (TS) and Attribute-Based Hill-climber (ABHC) in order to improve order batching mechanism which leads to minimisation in total travel distance and shorter computation time as well. The proposed algorithm also helps to reduce workload and the number of workers. Therefore, it may prove very useful for management of an organisation. The most important and challenging research areas proposed are interaction of batching with design issues in order to achieve improved order processing, resource utilisation and response time

(Henn and Wäscher, 2012). Further research can be conducted considering order due date and achieving global optimal solution. Henn (2012) replaced offline batching with on-line batching wherein orders become available dynamically while picking. They have proposed a model assuming capacity, number of pickers, batch size and class-based storage to minimise the maximum completion time of orders arriving within a certain time period. There is still an opportunity to reduce worker overtime and shorter lead times. This model needs to be tested in future with different storage policies and layouts. Moreover, minimising turnover times' competitive algorithms and results are missing.

The existing literature shows that different types of tradeoffs between performance issues have been addressed such as: picker speed versus capacity, efficiency versus response time, travel time versus storage delay, order completion time versus lead time, earliness versus tardiness, offline versus online batching and order completion time versus worker overtime. At the same time, while using different heuristics-based algorithms the number of constraints has been also relaxed or improved such as sorting, picker numbers, picker's capacity, throughput, congestion, number of workforce, offline batching and computation time. The main shortcoming of such an improvement or constructive type of algorithms is that they are basically solved under some assumptions or constraints. In real world practice, it is difficult to implement such algorithms with given assumptions, therefore simulation-based studies (for different configurations) or real world case studies are required to assist industry practitioners and model validation.

2.2 Routing concepts

Travelling in warehouse has been identified as the most expensive sub-process which accounts for around 60% of the total picking costs (Taljanovic and Salihbegovic, 2009). According to Rushton et al. (2006), traveling is the most time-consuming activity of moving from one to other picking location as it takes up around 50% of the total picking time. The subsequent activities are actual picking of goods and information retrieval which are not too time consuming. According to Tompkins et al. (2003) and Geng et al. (2005), travelling constitutes around 50 to 55% of the overall picking time. The travel time is a major cost and must be the first candidate for improvement (Bartholdi and Hackman, 2006). The overall material handling function is a combination of warehouse picking and forklift routing which can contribute around 20%-50% of total expenses (Tompkins et al. 2010; Vonolfen et al. 2012).

Before discussing the review of routing and sequencing, there are some basic routing policies that need to be discussed. Order sequencing is the process of arranging the visit of storage locations during picking operation in such a way that eliminates unnecessary travel time in order to improve system throughput (Hwang and Kim, 2005), which can be achieved by optimisation procedures or heuristics (Petersen and Aase, 2004). For a single block layout, Roodbergen (2001) proposed different routing policies like traversal, return, midpoint, largest gap and combined with definition. The same can also be used for multi-block warehouses with minor modifications. The choice of which aisle to visit can be decided by dynamic programming (Roodbergen and De Koster, 2001).

Some of the literature on routing policy is discussed here. Mainly all routing optimisation or improvement solutions are developed on the basis of Travelling Salesperson Problem (TSP). Ratliff and Rosenthal (1983) gave an optimal routing procedure in a rectangular warehouse with a number of assumptions such as narrow aisle, central depot as start and end point, two cross aisles and picking locations which are known in advance. This TSP problem can be extended to different warehouse situations that can or can't be solved using series–parallel graphs

(Cornue´jols et al. 1985; De Koster and Van der Poort, 1998; Roodbergen and De Koster, 2001). De Koster and Van der Poort (1998) presented an algorithm in order to determine optimal picking route in one block warehouse with decentralised depositing like a conveyer. Here they relaxed on constraint as the route can start and end up at the head of the aisle. Jarvis and McDowell (1991) estimated travel time and determined in which aisle the fast or slow moving items would be located. Similar work is being done by Lee Duc and De Koster (2004) using return heuristics. Caron et al. (1998) estimated the expected travel time for two routing methods in a two-block warehouse. Roodbergen and De Koster (2001) developed an optimal algorithm for three cross aisles warehouse by extending previously discussed model of Ratliff and Rosenthal (1983). For the first time Goetschalckx and Ratliff (1988) presented, a polynomial time algorithm to solve optimal routing problem in a wide-aisle warehouse. The problem with optimal routing is that the solution is not available for all types of layouts, the pickers see it as illogical to follow and it also doesn't consider the congestion (Gademann and Van De Velde, 2005; De Koster et al. 2007). Therefore, many studies focusing more on heuristics are required as it offers near optimal solution in lesser time and is also easy to implement (Hall, 1993).

Many studies found either solely or in combination focused on one or more routing policies with either storage or batching issue considerations. In their paper, Graves et al. (2002) have mentioned the research in routing with additional topics like use of technology, stochastic work levels (Bartholdi et al. 2001), alternate layouts (Caron et al. 2000), and kitting (Brynzer and Johansson, 1995) has been conducted. De Koster et al. (1999) performed a comparative study for multiple-aisle picker-to-parts systems using seed and time-saving heuristics considering travel time and number of batches as performance parameters. They found the seed algorithms are best in conjunction with the S-shape routing method and a large capacity of the picking device. Whereas the time-saving algorithms perform best in conjunction with the largest gap routing method and a small picking-device capacity. But the limitation of this study is that one or two of the three policy decisions (i.e., storage, routing, batching) has been assumed as fixed even though, they are interrelated and affecting overall performance. There is a correlation between stock accuracy and picking efficiency and proper storage policy can reduce travel distance (Burinskiene, 2010).

An ACO based meta-heuristics is used to optimise cost with given constraints for warehouse capacity and maximum distance to be travelled by pickers (Prasad and Shankar, 2011). Hwang et al. (2004) represented a model for various routing policies such as return, midpoint and s-shaped under various Cube over Index (COI based storage rules. Petersen's (1997) experiment with storage policy with different routing methods concluded that the best heuristics solution is on average 5% over the optimal solution. Roodbergen and De Koster (2001) analysed 80 multi-block warehouses with different routing policies and variable aisles and picking lists. They found that combined heuristics performs better in almost all warehouses. One major issue that may arise when the products are stored at different locations, is how to make the best choice for retrieval? Daniels et al. (1998) represented a model for simultaneous product assignment and multi-picker routings with the assumption that picking locations need to be selected before routing. Goetschalckx and Ratliff (1988) solved this problem where there is a trade-off between the time to start and stop the vehicle and the distance walked by the picker. Recently, Chen et al. (2013) proposed heuristics considering pick:walk-time ratio and congestion in multi-picker zone.

There is adequate literature on comparing various routing policies using optimal procedures, heuristics and simulations. Also, on the research time horizon we found that a number of assumptions have been relaxed such as demand distribution, its availability, layout configurations with varying number of aisles (parallel and cross), multiple picks, multi-product assignment, order side, Input-Output I/O locations and congestion.

2.3 Picking equipment

Typical order picking process involves picking case or unit quantities of products held on pallets in dedicated picking locations, checking and then assembling the goods, ready for packing and dispatching (Rushton et al. 2006). De Koster et al. (2007) classified the order picking system as per human involvement level wherein picker-to-goods and goods-to-picker are part of the system with manual interventions and robots. A-frame and dispenser are part of fully automated systems, operated without manual interventions. The decision of which picking equipment to adopt depends on a number of factors such as product size, weight, range of products, picking and order frequency, number of items per order and Storage Keeping Units (SKUs) per order. Basically it has been divided into three categories as picker-to-goods, goods-to-picker and automated system (Rushton et al. 2006) which can be used for travelling to pick up items. For the overall picking process, the type of equipment depends on what storage equipment the picker is picking from (e.g. shelves, flow racks or pallet locations), what equipment the picker is using (e.g. trolley, pallet truck) and what the picker is picking into or onto (e.g. wooden or roll cage pallet) as shown in Figure 1.

2.3.1 Picker-to-goods

Generally, the case or unit picking operations tend to be manually operated with the assistance of technology. But if the picker walks in warehouse for picking without assistance of any machine then it is called fully manually operated picking process. A picker-to-part (sometimes also referred as 'man-to-material' see Taljanovic and Salihbegovic, 2009) is a system where the order picker walks or rides a vehicle along picking locations in a warehouse (Henn and Wäscher, 2012). As the customer demand is not stable, the 'picker-to-part' is widely applied in production type of warehouses (Pan and Shih, 2008). Such parts are mentioned as mechanised in present taxonomy as they contain machine inactions.

2.3.1.1 Mechanised

De Koster et al. (2007) divided the picking equipment into two basic types as low-level and high-level picking. In the low-level picking system, the picker picks requested items from racks or bins where as a high-level picking system employs high storage racks and the picker picks items along with travelling over an automated truck or crane. Although various types of equipment are available, some of them listed by Rushton et al. (2006) are trolleys, roll-cage pallets, powered trucks/fork-lifts, free-path high-level picking trucks, fix-path high-level picking trucks, picking cars and conveyers. More sub-categorisation has been done as 'pick-to-tote' and 'pick-to-belt'. Armstrong et al. (1979) analysed the pick-to-belt warehouse system with sorting mechanism and evaluated the batching algorithms. De Koster (1996) used analytical expressions to approximate the maximum throughput by proposing a modeling and analysis method for pick-to-belt order picking system. De Koster et al. (2007) have introduced one more variant of method called 'put' system. It consists of a retrieval using picker-to-goods or goods-to-picker and then a bin with pre-picked units is offered (put) to a picker who distributes them over orders. Such a system is applicable where large numbers of customer lines are required to pick up in a small time window (e.g. Amozon, Flipcart) (De Koster et al. 2004).

We found many studies focusing on travel time reduction of picker, trolley, forklift or conveyer in a picker-to-part system as discussed here. Ho and Liu (2005) optimised the routing distance by converting the regular warehouse into a zone picking warehouse. The analysis done was on the basis of results for order-picking distance performance and its' mutual effects among different sources such as storage location, batching, clustering, routes and interactions among them. Hwang and Kim (2005) proposed an efficient cluster based batching heuristics for different routing policies in order to reduce total travel distance. The proposed algorithm works well for large batch size (number of batches>20) with less error rate (0.9%), otherwise seed algorithm performs better. Such algorithms are required to test and validate different warehouse configurations. Geng et al. (2005) used a Very Large Scale Neighborhood (VLSN) search approach to optimise travelling cost and distance for capacitated warehouse, where the maximum handling capacity of picking device can't be exceeded. They come up with the finding that VLSN outperforms SA algorithm in capacitated condition. Ding and Shi (2008) optimised the picking operation for distribution warehouse by reducing travel time and cost using community detection. Kutzelnigg (2011) considered fragile items in food industry and proposed a mixed integer programming model to develop heuristics and found up to 20% reduction in the total travel time.

Vonolfen et al. (2012) tried to integrate the picking with material handling between assembly line and warehouse. According to them, overall material handling, production and warehousing processes affect each other. The simulation results show that if pickers follow the sequence considering downstream transport requirement, then it leads to efficient transport management. When there are multiple pickers working simultaneously in picker-to-part system, there are chances of blockages or congestion (Gu et al. 2007). Again, here also there is a trade-off between travel distance and time delay due to congestion. Therefore, along with travel time, Pan et al. (2012) considered waiting time and average order fulfillment time in such systems. They proposed heuristics for storage assignment policy using queuing network in order to optimise multi-picker performance. They proposed a model determining number of aisles needed in order to balance travel time and distance according to the level of workforce. For the same picking system Yu and De Koster (2007) proposed an approximation method using G/G/m queuing network. Chen et al. (2013) proposed a heuristics based on Tabu search (TS), Ant colony optimization (ACO) (vary layout, order size and pick:walk-time ratio, etc) and other parameters to reduce congestion created by multiple pickers and suggested requirement of more realistic stochastic study.

Later on, they have relaxed some of their assumptions by extending the number of pickers with congestion consideration. Chen et al. (2014), proposed heuristics for online route forming with varying picking time without batching consideration. Still some of their assumptions like deterministic picker speed, no batching, order arrival time, capacity constraint needs relaxation in future. Online employees or pickers' workload balancing and distribution has also been identified as challenging issues in such environments. Further, this study could be extended to the real world application by combining routing with storage or batching which are a necessary part of the picking process. The tradeoffs between different parameters such as route length versus number of stops and destinations (Hall, 1993), holding time versus response time (Won and Olaffson, 2005), travel time versus delay (Pan and Shih, 2008; Vivaldiani et al. 2010), order completion time versus worker overtime (Henn, 2012), picking time versus response time (Chen et al. 2013, 2014) have also been addressed either fully or partially. Moreover, the performance metrics (i.e. picking time, picking capacity and speed, response time, waiting time with congestion, picking cost, storage cost, number of pickers, batch size) have also been analysed in order to achieve a more responsive system which is the requirement of existing business markets.

2.3.1.2 Manual

We found some studies solely on manual picking system as explained here. Hall (1993) conducted a study in manual warehouse to determine optimal route for different routing policies (i.e. largest gap, midpoint and traversal). Petersen and Aase (2004) examined the combined effects of policy decisions as an effort to determine strongest effect on system performance. They concluded that a solo optimal or sophisticated routing policy cannot result into savings as compared to combination with batching or class or volume-based storage policy. Eventually, they also found storage and batching to be more effective rather than routing for overall savings. They also found that the order size should be chosen with care while deciding policies whereas warehouse shape, I/O location and demand distribution have negligible effect on results. Le-Duc and De Koster (2005) take a 2-two block narrow aisle layout in picker-to-part manually operated warehouse to optimise storage zone and travel distance. They consider random, medium and skewed picking distributions and developed a heuristics based model. A Visual Basic (VB) based application was used for simulation and comparing results. The results turned out to be almost identical with minor differences in pick-list size. In future, more complex layout problems with return and traversal policies are expected to find out global optimal storage for each class and zone. This study requires more stochastic type of simulations combined with various other performance criteria.

Chan and Chan (2011) tried to improve productivity in multi-level rack distribution and manually operated warehouse while considering travel distance and retrieval time as measurement units. They suggested a study for layout design and congestion problems in case of multi-pickers in the same wave. Further, they have stated that overall logistics performance and customer service level can be improved by simulation with actual data in order to improve integration among warehouse activities. Taljanovic et al. (2011) focused on manual operation for multiple pickers with high volume, small parts and small orders. A queuing model based simulation was used as a research method and arena package for analysing the results. Henn and Wäscher (2012) studied manual distribution center and proposed meta-heuristics based on TS and ABHC in order to improve batching mechanism which leads to minimisation in total pickers' travel distance and shorter computation time as well. The proposed algorithm also helps to reduce workload and workers' overtime. Further research can be conducted considering order due date and how to achieve a global optimal solution. The interaction of order batching with related planning issues (e.g., picker routing, warehouse design, article location) has not been extensively studied. Henn and Schmid (2013) presented meta-heuristics for order batching and sequencing problem in order to minimise total tardiness of the system considering due dates. They conclude that implementing these solutions can improve customer service by delivering orders on time and by avoiding delays in other production stages. From shipping perspective Shiau and Liao (2013) improve picking efficiency (i.e. packaging costs and travel distance) in manual B2C distribution center with large batches of smaller quantities.

There is no review paper talking solely about a fully manually operated warehouse. Although there may be a number of such articles available, we have discussed the ones which are explicitly mentioned as 'manual'. Using heuristics, a number of assumptions had been relaxed such as different routing policies picking locations, distributions, aisle width, number of stops and destinations and I/O location and demand distribution. Some studies also talk about determining impact of varying order size and warehouse shape on routing performance. In a distribution center, multi-pickers with congestion and workforce level balancing has been also investigated. Many companies are still working with manual picking system because there is variability in SKU shape and size, the variability of demand, the seasonality of the products, or the large investment required for automated warehouse system and it is also not possible to change or upgrade it periodically for small and medium scale companies. Therefore, in future also, the manual intervention would always be there (Petersen and Aase, 2004). Global optimal solutions based on interaction of order batching and batch sequencing with other related planning issues (layout design, item location, picker routing) are required to be explored in future.

2.3.2 Goods-to-picker

Significant travel time of order picker can be reduced using highly mechanised system by controlling it with computer system (Rushton et al. 2006). Such a system is suitable for small items and also referred to as ‘material-to-man’ or ‘part-to-picker’ in literature as the required goods are represented in appropriate sequence to the picker. The picker takes the required number of parts and the remaining load is stored again (De Koster et al. 2007). It includes mainly AS/RS system, carousel, and miniload which is explained below along with literature studies in sequencing and routing issues.

2.3.2.1 AS/RS system

In pallet AS/RS, the aisle-bound crane is used that retrieves one or more pallets and brings them to the picking location or depot. The throughput is a major concern in this system and care must be taken that the storage utilisation is not adversely affected by the return of many part-empty pallets. It is also referred as a unit load or end-of-aisle picking system (Rushton et al. 2006). Sometimes, a person is involved in facilitating the operation along with the crane is called, man-on-board system. Such machines can work in different operating modes as single, dual and multiple command cycles. Bozer and White (1984) introduced some of the simple dwell point strategies which are static in terms of time, traffic and dynamic situation. Later on, this static constraint was upgraded to provide responsiveness (Egbelu, 1991). Dwell point policy is a set of rules deciding about the positioning of the crane while it is idle.

Some of studies found on unit load AS/RS system are explained here. Basically, the routing problems focused on interleaving problem where the roundtrip (dual command cycle) operation in terms of storage and retrieval is being tried to improve by reducing unproductive traveling between storage and retrieval (Graves et al. 1977). Elsayed (1981) presented some heuristic algorithms for handling orders in automated Storage/Retrieval (S/R) machine systems in order to minimise the total distance travelled. Hausman et al. (1976) conducted a study focusing on single command, unit load, single crane and storage assignment policies to optimise travel time of crane in an automated warehouse. They proposed a model considering different storage policies (i.e. random, turn over, class based) and travel time as performance measures. According to Gu et al. (2007), the sequencing problems can be categorised as static and dynamic. The static sequencing problems are the ones where the storage and retrieval sequence are fixed and can’t be changed. Such problems with class based and randomised storage is NP hard and different heuristics (Han et al. 1987; Sarker et al. 1991; Mahajan et al. 1998; Keserla and Peters, 1994) has been presented for it. Eben-Chaime (1992) and Ascheuer et al. (1999) have also found some other dynamic sequencing studies to improve travelling with optimal procedures. Kanet and Gonzalo-Ramirez (1986) considered costs of retrieval and location breakdown in order to evaluate sequencing policies in an AS/RS. Cormier (1995), and Linn and Xie (1993) have considered due dates and sequencing rules respectively, in order to represent algorithm for sequencing retrievals using dynamic programming. Seidmann (1988) proposed an adapted sequencing rule that incorporates seasonal demand fluctuations of the products. Bozer and Cho (2005) presented a study for an AS/RS under stochastic demand. Other major performance issues we found in literature of AS/RS system is chebyshev distance wherein same travelling of the crane or machine is considered in both horizontal and vertical direction. Shuhua and Yanzhu (2011) improved picking (by reducing storage-retrieval efforts) using TSP based recursive algorithm in a multi-aisle automated warehouse where each item is available in multiple locations. Some of constraints they assumed are constant crane speed; chebyshev routing and brake-start time of the crane is ignored. Hou et al. (2012) combined the features of ant colony-genetic algorithm and proposed hybrid heuristics to improve overall efficiency for stacker crane-automated warehouse. Fukunari and Malmborg (2008) and Gagliardi et al. (2012), found that all models are based on dynamic simulations while some also focused on static models optimising travel time. Further, they concluded that the static research analytical models for AS/RS requires validity testing using simulations for real-life applications. The performance of AS/RS depends upon interaction of many complex and stochastic subsystems which asks for robust and efficient evaluation models (Gagliardi et al. 2012). Meneghetti and Monti (2013) studied AS/RS dwell-point policies with storage assignment. They proposed three models of energy consumption while comparing traditional and new-generation cranes. The performance parameters taken into consideration are dedicated zone shapes, time and energy within a given timeframe.

2.3.2.2 Carousel

The carousel offers unit loads to the order picker. It is available in both vertical and horizontal mode. According to Rushton et al. (2006), in vertical mode the goods must be represented at the ideal picking height. It is also referred to as modular Vertical Lift Modules (VLM) (De Koster et al. 2007). The other variation of this system is available having several layers where each layer can be operated independently (Han et al. 1988).

Bartholdi and Platzman (1986) were the first ones to present some sequencing strategies for carousel systems. They argued that when order arrival rate is smaller than retrieval rate, picking sequencing within order matters while in the reverse case, the sequencing of orders must be considered in minimising unproductive time of travelling from the end position of one order to the start of next. Ghosh and Wells (1992) presented a dynamic programming approach in order to achieve optimal picking sequence. With same problem Van Den Berg (1996) considered the case when both in-order and between-order picking sequences are to be determined by assuming that each order is picked along its shortest spanning interval. They ignored perpendicular travel to the rotation of the carousel. Rouwenhorst et al. (1996) proposed a stochastic model in order to determine the maximum throughput and the response time of a carousel system. Spee (1996) optimised throughput of a carousel system in combination with a picking robot. Wen and Chang (1988) proposed heuristics with a two-dimensional consideration. Mainly all travel models in dual-command cycle assume infinite acceleration in order to simplify the travelling models. For various axis motions (Hwang and Lee, 1990; Hwang et al. 2004; Chang and Wen, 1997; Chang et al. 1995) have proposed a model considering acceleration. Han and McGinnis (1986) and Han et al. (1988) extended the dual-command AS/RS to carousels and rotary racks using the nearest-neighbor heuristics. In dual-command the basic issue identified by Gu et al. (2010), is matching up storages and retrievals to minimise dead-head travel of the crane. This is basically influenced by retrieval sequencing and storage locations. The distribution of travel time is also a major issue that needs a mathematical model (Foley et al. 2002). The throughput of carousel systems is modeled by Park et al. (2003), considering a system with two carousels and one picker, and derives analytic expressions for picker utilisation assuming deterministic and exponential picking time distributions. Meller and Klote (2004) developed throughput models for systems with multiple carousels using an approximate two-server queuing model approach.

2.3.2.3 Miniload

It is the same system as pallet AS/RS but here the aisle-bound crane is used that retrieves one or more tote bins or cartons and brings them to the picking location or depot. The items are stored in modular storage drawers or in bins. These containers may be subdivided into multiple compartments each containing a specific SKU. The remaining goods are then returned to the storage location. Individual studies on miniload are very scarce, however in combination with other systems there is some research available. Foley and Frazelle (1991) presented a model to optimise throughput of a miniload system by deriving closed-form analytical expressions. Mahajan et al. (1998) proposed heuristics for static sequencing in dual-command mode and random storage to improve end-of-aisle miniload. In their handbook Rushton et al. (2006) suggested how a new hybrid efficient system can be formed with combination (using miniload for dynamic face picking and manually from aisles to conveyers) of picker-to-goods called ‘goods-to-aisle’. Pickers are travelling past many SKUs that are not required by any order at that time. Therefore, only those goods are placed in the aisles which are required during that wave and this is called dynamic picking phase. It is normally used for slow moving lines.

There is adequate literature available in this particular category that states that issues such as operating time, picking time, static and dynamic sequencing, chebyshev distance optimisation, dwell point policy and idle time optimisation, single and double cycle have been already addressed. Still some unaddressed constraints are demand known and constant, pickup/drop and acceleration time ignored and FIFO serving. Moreover, more variation in storage and other policies is required to be tested for further validation of existing models. Initially, carousel and miniload research was in line with AS/RS system but, in recent literature we found more papers focus only on AS/RS systems. Therefore, further explorative or comparative study of these required. Elsayed et al. (1993) extended the same problem with penalties for early retrieval under JIT environment. Linn and Xie (1993), and Lee and Kim (1995) think from lean perspective in AS/RS system. They have presented heuristics sequencing storage/retrieval requests in order to improve due date performance. Here, the important issue is that they considered JIT performance as an important metric rather than minimisation of operational costs. Although for storage and handling systems, some insights are provided by Shah and Khanzode (in-press), more exploration in this direction is further required.

2.3.3 Automated systems

The ‘automated’ warehouse can work effectively without direct operatives in reserve storage area. High level of accuracy and productivity can be achieved using such advanced equipments and IT appliances. It is used in special cases and applications where items are valuable, small and delicate (De Koster et al. 2007). Some of the automated systems described (refer Rushton et al. 2006 for further detail) are layer pickers, dispensers and robots. An A-frame is order-picking device without pickers. It consists of a conveyer belt with magazines arranged in A-frame style on either side of belt (refer Van den Berg and Zijm, 1999 for further detail). It provides high throughput and response time but is very expensive. (Rouwenhorst et al. 2000). Kim et al. (2003) optimised order picking sequence using sorting heuristics and cluster-based algorithm in an automated warehouse where layout length is larger than width and the picker picks just one item at a time. They optimise and change proposed algorithm for efficient use of gantry robot using drop buffer time assignment. Vivaldini et al. (2010) proposed a Dijkstra’s algorithm to produce an optimal route considering obstacles and conflicts (deadlock) for robot forklifts called Automated Guided Vehicle (AGV). Future scope is there to relax the vehicle speed variation constraint. In this review, we found more papers concerning automated applications as explained here: Fa-liang et al. (2007) proposed a model for picking optimisation in an automated warehouse. They proposed GA based improved model which seems effective, reliable, energy efficient and can enhance the picking efficiency. Further, this approach can also be helpful for solving combined optimisation and NP-hard problems. Zhang and Zhang (2010) improved the picking operations by presenting a schedule algorithm in bend aisle, stereoscopic automated type of warehouse.

Major studies exist on picker-to-part and AS/RS in part-to-picker categories. Rare studies are available on fully automated systems, whereas some are available on fully manually operated picking systems. The research on carousel travel time models should be parallel to corresponding AS/RS research.

2.4 Sorting

If the goods have been picked up by a batch or zone, then the sorting system requires to sort customer orders before dispatching. The sorting can be carried out either manually or with the assistance of some form of mechanised (e.g. conveyer) system. It can be performed after picking or packing depending on the requirement of the system. Moreover, it plays a vital role in improving responsiveness of customer orders (Rouwenhorst et al. 2000). Some of the sorting systems are sliding shoe, tilt-tray and cross-belt sorters.

A batch formation algorithm for multi aisles AS/RS system with sorting supports has been proposed (Elsayed 1981). There are various types of Order Aand Sorting Systems (OASS) available ranging from manual staging using a kitting matrix to high volume automatic systems. Carousels and rotary racks are used for the accumulation and sorting of orders (Van den Berg and Zijm, 1999). For a small number of large and dedicated order lane system, Bozer and Sharp (1985) analysed the relationship between throughput and other factors using simulation and found throughput depends upon the induction capacity, the number of lanes, and the length of lanes. Bozer et al. (1988) have considered the same problem but here each lane is assigned several orders and an order-to-lane assignment policy determines how and when the orders enter the sorting lanes. Using simulation, they compare different order-to-lane assignment rules and find out that the First Come, First Served (FCFS) rule consistently outperforms more elaborated rules. Later on, Meller (1997), tried to optimise the sorting time using order-to-lane assignment method for a pick-wave. Finally Gu etal. (2007) concluded that, if orders are distributed in a balanced way into pick waves then heuristics to solve it is an adequate rather than optimal solution. Johnson and Meller (2002) have analysed throughput of sorting systems and found induction process as bottleneck which governs system performance. Later on, Russell and Meller (2003) extended this model by integrating picking and sorting to balance the tradeoffs between picking and packing with different order batch sizes and wave lengths. Using this model at the time of design we can also decide whether to adopt automated or manual sorting system. No further studies were found on sorting related issues.

2.5 Layout and slotting

The decision of forward-reserve storage with respect to layout is critical as it influences the productivity. The process of identification of individual SKUs to be located in each location is called ‘slotting’. The Pareto analysis is the best solution of slotting to identify the order lines as per its sales. Some of the other possible solutions are location nearby depot, location by weight or location by store layout (Rushton et al. 2006). Kutzelnigg (2011) reduced mean picking distance in food warehouse by providing location by weight slotting. Further, they identified more research gaps possible for improvement using meta-heuristics in food (perishable) or retail warehouses. According to Ronald et al. (2007), overtime for picking can be optimised using Order Oriented Slotting Strategy (OOSS). Papers on these issues are completely missing even though it improves the material flow in the warehouse.

2.6 Replenishment

The replenishment procedure should ensure full stock availability. The incomplete replenishment violates service level in the form of incomplete orders, or extra cost because of the need for pickers to revisit picking locations. For picking it is recommended to have smallest forward area in order to reduce travelling cost but on the other hand, there are more efforts required in this case for replenishment. According to Rushton et al. (2006), there is a tradeoff between picking and replenishment efforts. The replenishment workloads can be reduced using flow racks which supports more inventories in less space. Taljanovic and Salihbegovic (2009) focused on wave planning and try to improve overall throughput in warehouse including replenishment, picking and shipment activities. They achieved improvement in replenishment cost, picking time, worker productivity and labour cost. Some of solutions suggested by (Rushton et al. 2006), are real-time computer systems and flow racks where once the unit load is empty, or the item is issued from the stock, the next one rolls forward and is immediately available for use. Hackman and Rosenblatt (1990) proposed a knapsack based heuristics in order to minimise the total material handling costs of order picking and replenishing. In extension of this, Frazelle et al. (1994) treated the size of the forward area as a decision variable and optimised the cost for picking and replenishment with the assumption of single trip SKU replenishment. Van den Berg et al. (1998) considered the problem for unit-load replenishments where the forward area can be replenished instantly with busy and idle periods. Therefore, it is possible to reduce the number of replenishments during busy periods by performing replenishments in the preceding idle periods. They have reduced expected total labour-time related to order-picking and replenishing during a busy period. The consideration of replenishment in order to improve picking operations is not fully explored yet.

2.7 Picking productivity and e-fulfillment

Good information and communication system is necessary to deliver the customer order accurately within a given timeline. Basically picking information required by the picker includes the picking locations and its sequence to be visited, the order quantities and SKUs to be picked and its destination. Numbers of information systems and methods can be adopted in order to improve picking operations (e.g. picked by label, bar codes, radio terminals, pick by light, put to light and voice technology, Rushton et al. 2006).

Some of the papers found for such systems are discussed here. Sharp et al. (1996) presented a case study and compared pick-to-light systems with alternative systems through both a quantitative and a qualitative criteria. The simulation results show that the extended picking model of pick-and-pass with voice capability allows very fast and accurate picking of high volume, small items of orders where serial numbers are not required (Taljanovic et al. 2011). Chen et al. (2014) have proposed heuristics for online route forming with varying picking time. Online employees or pickers workload balancing and distribution has also been identified as challenging issues in such environments. Johnston et al. (1999) shows the application of geographical information system (GIS)-based software system to manage and integrate multi facility warehousing and production systems that are distributed within a relatively large geographical area. Gunasekaran et al. (1999) conducted a case study and presented a conceptual framework considering JIT, TQM and IT applications in order to improve warehouse operations. Ding and Shi (2008) optimised picking using social network and community detection for identifying the items which may be picked together in one picking operation. Further error rate and productivity in picking operations can be improved by 50% with Computer Aided Picking System (CAPS) and information technology enabled tools like bar code identification, radio frequency terminals, and pick-to-light systems (Jane and Laih, 2005; Pan and Wu, 2009; Tompkins et al. 2003). According to Ho and Sarma (2009), automatic identification and tracking technologies like Radio Frequency Identifier (RFID), wi-fi, etc make it feasible to store goods in free form but all warehouses cannot afford to implement such capital-extensive technologies. Some sophisticated storage and retrieval approach is required that deals with external issues such as demand and supply variability in order to optimise overall picking operation. Lam et al. (2012) have presented a hybrid approach called the Case-Genetic Algorithm-based Decision Support model (C-GADS) that helps to enhance the effectiveness of formulating warehouse order operations. As a future scope of this model, the authors have suggested to test this model for picking process.

Nowadays, online order placing via internet technologies and e-commerce business demands more responsive supply chains (Van den Berg and Zijm, 1999). According to Rushton et al. (2006) the picking workloads can be improved in such e-fulfillment systems where large numbers of small customer orders are there asking for a large variety, low price and good quality products within a short span of time. To be more demand-responsive, companies are following ‘Pull’ supply chain model, where customer’s demand drives production activities (Hoekstra and Romme, 1992). The online shopping causes retailers and distributors to hold all product varieties in sufficient quantity, failure of which reduces service level and increases opportunity lost cost (Van den Berg and Zijm, 1999; Ho and Liu, 2005; Bozer and Kile, 2008). There is a tradeoff between time, cost and operations efficiency. Therefore, research is required to target such types of products (perishable/food) and warehouse (retail/distribution) where, adequate inventory are required to guarantee customer satisfaction with product varieties and shorter response time as well. High service level and shorter response time may lead to cost savings in downstream supply chain but it does exert pressure on companies to adopt lean or JIT philosophy (Van den Berg and Zijm, 1999). Shah and Ward (2003) suggested that productivity and customer lead time can be improved using lean applications. Sobanski (2009) proposed a model for lean assessment in warehouse in order to identify basic constructs, lean tools and validate it using factor analysis.

The picking performance can be measured with reference to the picking rate which can be expressed as the number of items per hour, picks per person per hour, number of SKUs or order lines per hour. Other performance indicators are also there such as picking-response-waiting time, storage policy, dispatch accuracy and resource utilisation, which can result in waste reduction and productivity improvement with proper management (Sharma and Shah, 2015). According to Rushton et al. (2006) there are also other important issues affecting effectiveness of picking operations like the way stock is laid within the picking area, eliminate waiting time, balancing workloads across picking staff, ensuring timely replenishment, interfacing planning between picking and packing operation. Emami et al. (2014) presented a simulation study in order to reduce waiting time while loading in warehouse. Many studies directly or indirectly focus on improvement of picking productivity, either individual or in combination with routing, storage or batching are explained in this paper. The performance and productivity of an order picking system also depends on the demand pattern of the items, the layout of the warehouse, storage process, batching method and routing method (Petersen, 1999).

Most of the papers we found and referred to until now are focusing on picking optimisation and efficiency. There are studies available in routing, batching and storage optimisation with major performance issues like travel time, cost and storage space utilisation. However, issues targeting effectiveness such as timeliness of meeting dispatch deadlines, rejects and stock damage are still ignored. Waiting time, workload balancing across picking staff interfacing planning between picking and packing operations within the warehouse have been explored up to some extent. But still more realistic case studies with stochastic and simulation assumptions are required. Further, IT applications (e.g. GPS, GIS, RFID) improve productivity which requires more research in order to support warehouse industries.

3. Findings and Discussion

Although each individual sub-section has been concluded with important findings and its impact on performance, this section converges some important research findings. The numbers within parenthesis along with titles in Figure 3 indicate the number of related papers found in current m literature. Out of the specified, some of the references are redundant and some of basic definitions have been ignored. From this classification-based review, it is clear that more emphasis has been given to research in picking concepts and picking equipment. In picking concept, more importance is given to optimise the picking capacity through batching and efficiency through zoning respectively. We found that the reason for more emphasis on picking equipment in literature is to improve travel time or distance and picking sequences. The quicker order processing improves response time and customer service level as well. The routing concepts, productivity and e-fulfillment have been given adequate justification. Further research on IT applications would contribute to improve responsiveness. If we see in next level of the same section then, fully automated have been slightly neglected by the researchers as compared to the picker-to-goods and goods-to-picker process. Further, manually operated warehouses have also been ignored. Up to some extent sorting, slotting and replenishment are also not properly studied even though their contribution is vital. Some of the major findings or guidelines are discussed below.

In warehouse, the wave and zoning improves material flow but wave hasn’t been given adequate importance. Zoning also has been applied to reduce congestion and to improve throughput. But, these issues are required to focus at design level. Nowadays, utmost operations are carried out with assistance of machinery or automation. Therefore, workload balancing and distribution would demand dynamic management in future, particularly in fully or semi-operated warehouses. Batching has been explored upto online support while picking, but still it can be combined with different storage policies and layout designs in order to manage picking and response time tradeoffs. Further, we found cycle time, cost, customer service level and productivity (i.e., resource utilisation) as performance metrics focused frequently on operational level. Different authors considered different Key Performance Indicators (KPIs) in existing literature and also tried to improve these measures independently or in combination. But almost all studies resulted in tradeoffs among these performance measures. The replenishment can be further explored along with storage allocation and sizing issues at design level. Though AS/RS and picking operations have been studied from the routing perspective, the handling and storage integrated models would be more important in the future.

There are a numbers of optimisation algorithms (like PSO, SA, neural network algorithm, GA, ACO, TS and ABHC etc.) found in order to improve warehouse operations having own benefits and shortcomings. Many authors tried to combine one or more such algorithms to improve overall outcomes. Further, research gap has been found in order to improve computation time and global optimal solution in various functions. However, the main shortcoming of such improvement or constructive type of algorithms is that, they are basically solved with enormous assumptions or constraints. In real world practice, it is difficult to implement such algorithms with given assumptions (Moeller, 2011), therefore more simulation- based studies or real world case studies are required to explore demonstrating practical applicability. Further, isolated solutions have been provided for such problems which are inadequate and it may result in globally sub-optimal performance (Rouwenhorst et al. 2000; Volonfen et al. 2012). Therefore some robust solution is required which fosters the overall performance and responsiveness.

The growing varieties and demands of products insist the retailers to use the available storage space efficiently (Gajjar and Adil, 2011), therefore optimizstion research focusing storage and related issue is the most challenging area and will be encouraged due to internet order processing and e-commerce. In future, this issue is more challenging from the research point of view as it also affects production warehouse design, planning and control operations. The picking policies have been fully explored as major operational studies are on picking and routing optimisation but, we have not included layout, storage and routing policies fully as they are considered as part of design rather than operational issues.

4. Conclusions and Future directions

Review papers in warehouse operations have been extensively explored with different research contexts; nevertheless we believe this paper is unique of its kind for researchers as it highlights important conclusions derived under various constraints and circumstances. The problem identified in previous operational review papers is that it was very difficult to club together the related research papers. Some of authors tried to categorize the papers and presented design (Rouwenhorst et al. 2000) and operational issues but, those are confined to the scope of isolated functions like picking (de Koster et al. 2007), storage (Gu et al. 2007; Roodbergen and Vis, 2009; Gagliardi et al. 2012) and receiving-shipping. Gu et al. (2010) explored performance measures affecting design decisions, but operational issues were unaddressed. Recently, Staudt et al. (2015) categorised warehousing literature on the basis of performance dimensions and indicators. This paper also addresses the research gap through a taxonomy combining all related warehousing operations, storage-handling devices and measures affecting productivity. It also tries to identify the measures, methods and their impact on overall logistics performance. To best of our knowledge, this is the most comprehensive and exhaustive review. However, its scope is limited to performance measures and methods addressing operational issues only.

Although some straight and in-depth research gaps have been discussed throughout this paper for every issue, broader research gaps are listed below. These gaps would provide a future road map for research in existing and other unexplored areas of warehouse operations and management.

- As result of emerging e-commerce and internet applications in distribution centers, there is a need for a model adopting JIT philosophy in order to provide efficient storages and responsive warehousing ensuring optimal costs, throughput and service level.
- Proper employee workload distribution and balancing policies require more exploration particularly in manual warehouse.
- The tradeoffs among different performance measures have been fully explored at operational level. Further extension to these studies using simulation and case studies will provide more validated and accepted models by the practitioners (Davarzani and Norrma, 2015).

- Isolated studies found at operational level in order to achieve local optimal solutions using assumption based heuristics (mainly NP hard problems). This can be further extended to improve computation time and global optimal solution using meta-heuristics or evolutionary algorithms for every functional area.
- The tradeoffs between picking efficiency and order responsiveness could be studied with different stochastic issues (worker overtime, earliness, tardiness, penalty, order due date, costs, etc). Also, many studies have been found solely for picking efficiency but the integrated model including responsiveness may provide better results.
- The in-process storage stream lining by an integrated approach of storage and handling may be helpful for production type of warehouse.
- As identified by Van den berg and Zijm (1999), JIT perspective may be explored for the warehouses (food or production) where material availability and time are more important than operational costs. This is still an unexplored area.
- Since 2000, the trend of using IT systems is identified as enhancing overall productivity in warehouse (Gunasekaran et al. 1999), but the review trend shows that research papers integrating warehouse operations with GIS, GPS, SAP, RFID and other computer applications is still not up to a satisfactory level as compared to e-commerce adoption in customer ordering. This gap is overlooked by researchers and must be addressed in future which can improve decision making abilities of managers enhancing operations through service levels.
- Online routing and batching have been addressed solely. A combined approach with an expert decision tool helps determining number of workers, machines, their workload distribution and balancing.
- Although it has been proved from literature that an integrated model considering sorting, replenishment, slotting and wave picking helps to improve material flow and responsiveness, its application in industry is still an unexplored area.
- The present state-of-the-art of literature considers different key performance indicators (KPIs) and tries to improve these KPIs independently or in combination with other parametres.. But as per this review, almost all studies resulted in tradeoffs among these performance measures. As some of them are also identified as waste contributors; a lean philosophy could be adopted in order to reduce these wastes. Shah and Khanzode (in press) have thought storage and handling devices' design issues from lean perspective which needs more research exploration in future.
- As only a single empirical lean survey is available on warehousing (Sobanski, 2009), more exploration in this area would help the researchers to determine performance issues and its impact on leanness.
- As operational performance is affected by design level decisions, a combined research approach of design and operational issues has been emphasised.

References

Armstrong, R.D., Cook, W.D. and Saipe, A.L. (1979). 'Optimal batching in a semi-automated order picking system'. *Journal of the Operational Research Society* 30 (8), pp.711-20.

Ascheuer, N., Grotschel, M. and Abdel-Hamid, A.A.A. (1999). 'Order picking in an automatic warehouse: Solving online asymmetric TSPs'. *Mathematical Methods of Operations Research* 49 (3), pp.501-515.

Ashayeri, J. and Goetschalckx, M., (1989). 'Analysis and design of order pick systems'. Proceedings of the 9th International Conference on Automation in Warehousing, pp.125-135.

Bachers, R., Dangelmeier, W. and Warnecke, H.J. (1988). 'Selection and use of orderpicking strategies in a high-bay warehouse.Mater'. Flow, 4, pp.233-245.

Bartholdi, J., Bunimovich, L.A. and Eisenstein, D. (1999). 'Dynamics of two- and three-worker ''bucket brigade'' production lines'. Operations Research 47 (3), pp. 488-91.

Bartholdi, J., Eisenstein, D. and Foley, R. (2001). 'Performance of bucket brigades when work is stochastic'. Operations Research 49 (5), pp.10-719.

Bartholdi, J. and Hackman, S.T. (2006). Warehouse & distribution science, release 0.85, available at http://www.warehouse-science.com, accessed May 27, 2009.

Bartholdi, J.J. and Platzman, L.K. (1986). 'Retrieval strategies for a carousel conveyor'. IIE Transactions 18 (2), pp. 166-73.

Bozer, Y.A. and Cho, M. (2005). 'Throughput performance of automated storage/retrieval systems under stochastic demand'. IIE Transactions 37 (4), pp. 367-378.

Bozer, Y.A. and Kile, J. W. (2008). 'Order batching in walk-and-pick order picking systems'. International Journal of Production Research 46, 7, pp. 1887-909.

Bozer, Y.A. and Sharp, G.P. (1985). 'An empirical evaluation of a general purpose automated order accumulation and sortation system used in batch picking'. Material flow (2), 2-3, pp.111-131.

Bozer, Y.A. and White, J.A. (1984). 'Travel-time models for automated storage and retrieval system'. IIE Transactions, 16 (4), pp. 329-38.

Bukchin, Y., Khmelnitsky, E. and Yakuel, P. (2012). 'Optimizing a dynamic order-picking process'. European Journal of Operational Research 219, pp.335-346.

Burinskiene, A. (2010). 'Order picking process at warehouses'. International Journal of Logistics Systems and Management, Vol. 6, No.2 pp. 16

2- 178. Caron, F., Marchet, G. and Perego, A. (2000). 'Optimal Layout in Low Level Picker-to-Part Systems'. International Journal of Production Research38 (1), pp.101-117.

Chan, H. K., Chan, F. T. S. (2011). 'Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage'. Expert systems with Applications 38, pp. 2686-2700.

Chang, D.T. and Wen, U.-P. (1997). 'The impact of rack configuration on the speed profile of the storage and retrieval machine'. IIE Transactions 29, pp.25–531.

Chang, D.-T., Wen, U.-P.and Lin, J.T. (1995). 'The impact of acceleration/deceleration on travel-time models for automated storage/retrieval systems'. IIE Transactions 27, pp.108–111.

Chen, F. Y., Wang, H. W., Qi, C., and Xie, Y. (2013). 'An ant colony optimisation routing algorithm for two order pickers with congestion consideration'. Computers & Industrial Engineering, 66(1), pp.77–85.

Chen, F., Wang, H., Xie, Y. and Qi, C. (2014). 'An ACO-based online routing method for multiple order pickers with congestion consideration in warehouse'. Journal of Intelligent Manufacturing.

Chen, M.C. and Wu, H.P. (2005). 'An association-based clustering approach to order batching considering customer demand patterns'. Omega International Journal of Management Science 33 (4), pp.333–343.

Chen, M.-C., Huang, C.-L., Chen, K.-Y.and Wu, H.-P. (2005). ‘Aggregation of orders in distribution centers using data mining’. Expert Systems with Applications 28 (3), pp.453–460.

Chew, E.P. and Tang, L.C. (1999). ‘Travel time analysis for general item location assignment in a rectangular warehouse’. European Journal of Operational Research 112, pp. 582–597.

Choe, K. and Sharp, G.P. (1991). ‘Small parts order picking: design and operation’. http://isye.gatech.edu/logisticstutorial/order/article.htm, accessed in July 2012.

Choe, K., Sharp, G.P. and Serfozo, R.S. (1993). ‘Aisle-based order pick systems with batching, zoning and sorting’. In: Progress in Material Handling Research, 1992, pp. 245–276.

Cormier, G. (1995). ‘A brief survey of operations research models for warehouse design and operation’. Report, Bulletin, CORS- SCRO.

Coyle, J. J., Bardi, E. J., and Langley, C. J. (1996).The management of business logistics. MN: West: St. Paul.

Dai, H. and Tseng, M.M. (2011). ‘Determination of production lot size and DC location in manufacturer–DC–retailer supply chains’. International Journal of Logistics Systems and Management, Vol. 8, No.3 pp. 284 -297.

De Koster, R. (1996). ‘On the design of a high capacity pick-and pass order picking system,’ in: Progress in Material Handling Research, The Material Handling Industry of America, Charlotte, NC, 1996, pp. 253-269.

De Koster, R. (1994). ‘Performance approximation of pick-to-belt orderpicking systems’. European Journal of Operational Research 72, pp. 558-573.

De Koster, R. and Van Der Poort, E. (1998). ‘Routing order pickers in a warehouse: a comparison between optimal and heuristic solutions’. IIE Transactions 30, pp.469–480.

De Koster, R., Le-Duc, T. and Roodbergen, K. J. (2007). ‘Design and control of warehouse order picking: A literature review’. European Journal of Operational Research 182, pp.481-501.

De Koster, R., Van der Poort, E.S. and Wolters, M. (1999), ‘Efficient order batching methods in warehouses’. International Journal of Production Research 37 (7), pp.1479–1504.

Ding, L. and Shi, P. (2008). ‘Efficient Order Picking Based on Community Detection’. IEEE. pp.2289-2294.

Drury, J. ‘Towards more efficient order picking’, (1988) IMM Monograph No. 1, The Institute of Materials Management, Cranfield, U.K.

Dukic, G. and Oluic, C. (2007). ‘Order-picking methods: improving order-picking efficiency’. INternational Journal of Logistics Systems and Management, Vol. 3, No.4 pp. 451 – 460.

Eben-Chaime, M. (1992). ‘Operations sequencing in automated warehousing systems’. International Journal of Production Research (30), 10.

Egbelu, P.J. (1991). ‘Framework for dynamic positioning of storage/retrieval machines in an automated storage/retrieval system’. International Journal of Production Research 29 (1), pp.17–37.

Elsayed, E.A. (1981). ‘Algorithms for optimal material handling in automatic warehousing systems’. International Journal of Production Research 19 (5), pp. 525–535.

Elsayed, E.A. and Lee, M.K. (1996). ‘Order processing in automated storage/retrieval systems with due dates’. International Journal of Production Research 28 (7), pp.567–577.

Elsayed, E.A. and Stern, R.G. (1983). ‘Computerized algorithms for order processing in automated warehousing systems’, International Journal of Production Research 21 (4), pp.579-586.

Elsayed, E.A. and Unal, O.I. (1989). ‘Order batching algorithms and travel-time estimation for automated storage/retrieval systems’. International Journal of Production Research 27, pp.1097–1114.

Elsayed, E.A., Lee, M.-K., Kim, S. and Scherer, E. (1993). ‘Sequencing and batching procedures for minimizing earliness and tardiness penalty of order retrievals’, International Journal of Production Research 31 (3), pp. 727-738.

Emami, S. B., Arabzad, S. M. and Sajjadi, S. M. (2014). ‘A simulation study on warehouse loading system: the case of poultry feed production factory’. International Journal of Logistics Systems and Management, Vol. 19, No.3 pp. 347 – 355.

Fa-liang, C., Zeng-xiao, L., Zheng, X. and Dong-dong. L. (2007). ‘Research on Order Picking Optimisation Problem of Automated Warehouse’. Systems Engineering-Theory and Practice 27, 2, pp.139-143.

Foley, R., Frazelle, E.H. and Park, B.C. (2002). ‘Throughput bounds for miniload automated storage/retrieval systems’. IIE Transactions 34 (10), pp.915–920.

Frazelle, E. (2002)a. Supply Chain Strategy: The Logistics of Supply Chain Management. McGraw-Hill, New York.

Frazelle, E. (2002)b. World-class Warehousing and Material Handling. McGraw-Hill, New York.

Frazelle, E.H., Hackman, S.T., Passy, U. and Platzman, L.K. (1994). ‘The forward–reserve problem. In: Ciriani, T.C., Leachman, R.C. (Eds.)’, Optimisation in Industry 2. Wiley, New York, pp. 43–61.

Fukunari, M. and Malmborg, C.J. (2008). ‘A heuristic travel-time model for random storage systems using closest open location load dispatching’. International Journal of Production Research, 46 (8), pp. 2215–2228.

Gademann, N. and Van de Velde, S. (2005). ‘Order batching to minimize total travel time in a parallel-aisle warehouse’. IIE Transactions 37, pp.63–75.

Gagliardi, J. P., Renaud, J. and Ruiz, A. (2012). ‘Models for automated storage and retrieval systems: a literature review’. International Journal of Production Research 50, 24, pp.7110-7125.

Gajjar, H.K. and Adil, G.K. (2011). ‘Heuristics for retail shelf space allocation problem with linear profit function’. International Journal of Retail & Distribution Management 39, 2, pp.144-155.

Geng, Y., Yanzhi Li, Y. and Lim, A. (2005). ‘A Very Large-Scale Neighborhood Search Approach to Capacitated Warehouse Routing Problem’. IEEE International Conference on Tools with Artificial Intelligence 17.

Ghosh, J.B. and Wells, C.E. (1992). ‘Optimal retrieval strategies for carousel conveyors’. Mathematical Computer Modelling 16 (10), pp.59-70.

Gibson, D.R. and Sharp, G.P. (1991). Order batching procedures, Technical Report MHRC-TR-90-05, Georgia Institute of Technology, Atlanta, GA

Gibson, D.R. and Sharp, G.P. (1992). ‘Order batching procedures’. European Journal of Operational Research 58 (1), pp.57-7.

Goetschalckx, M. and Ashayeri, J. (1989). ‘Classification and design of order picking systems’. Logistics World (June), pp. 99–106.

Goetschalckx, M. and Ratliff, H.D. (1988). ‘Order picking in an aisle’. IIE Transactions 20, pp.53-32.

Graves et al. (Eds.), Progress in Material Handling Research: (2002). Material Handling Institute, Charlotte, pp. 51–69.

Gray, A.E., Karmarkar, U.S. and Seidmann, A. (1992). 'Design and operation of an order-consolidation warehouse: Models and application', European Journal of Operational Research 58 (1), pp. 14-36.

Gu, J.X., Goetschalckx, M. and McGinnis, L.F. (2007). 'Research on warehouse operation: A comprehensive review'. European Journal of Operational Research 177 (1), pp.1-21.

Gu, J.X., Goetschalckx, M. and McGinnis, L.F. (2010). 'Research on warehouse design and performance evaluation: A comprehensive review'. European Journal of Operational Research 203, pp.539-549.

Gunasekaran, A., Marri, H.B. and Menci, F. (1999). 'Improving the effectiveness of warehousing operations: a case study'. Industrial Management and Data Systems, 99/8, 328-339.

Hall, R.W. (1993). 'Distance approximations for routing manual pickers in a warehouse'. IIE Transactions 25(4), pp.76-87.

Han, M.H., McGinnis, L.F. and White, J.A. (1988). 'Analysis of rotary rack operation'. Material Flow 4, pp.283-293.

Han, M.H., McGinnis, L.F., Shieh, J.S. and White, J.A. (1987). 'On sequencing retrievals in an automated storage/retrieval system'. IIE Transactions 19 (1), pp.56-66.

Haq, A. N. and Kannan, G. (2006). 'Two-echelon distribution-inventory supply chain model for the bread industry using genetic algorithm'. International Journal of Logistics Systems and Management, Vol. 2, No.2 pp. 177- 93.

Hausman, W. H., Schwarz, L. B. and Graves, S.C. (1976). 'Optimal storage assignment in automatic warehousing systems'. Management science 22, (6), pp.629-693.

Henn, S. (2012). 'Algorithms for on-line batching in an order picking warehouse'. Computers and Operations Research, 39, pp. 2549-2563.

Henn, S. and Schmid, V. (2013). 'Metaheuristics for order batching and sequencing in manual order picking systems'. Computers and Industrial Engineering, 66, pp.338-351.

Henn, S. and Wäscher, G. (2012). 'Tabu search heuristics for the order batching problem in manual order picking systems'. European journal of Operational Research 222. pp. 484-494.

Heragu, S.S., Du, L., Mantel, R. J. and Schuur, P. C. (2005). 'Mathematical model for warehouse design and product allocation'. International Journal of Production Research 43, 2, pp.327-338.

Ho, S.S. and Sarma, S. (2009). 'The Fragmented Warehouse: Location Assignment for Multi-item Picking'. IEEE.

Ho, Y.C. and Liu, C.F. (2005). A design methodology for converting a regular warehouse into a zone-picking warehouse'. Journal of Chinese Institute of Industrial Engineering (22), 4. pp. 332-345.

Hoda Davarzani, H. and Norrman, A. (2015). 'Toward a relevant agenda for warehousing research: literature review and practitioners' input'. Logistics Research 8:1.

Hoekstra, S. and Romme, J.H.J.M. (Eds.), (1992). Integral Logistic Structures: Developing Customer Oriented Goods Flows, McGraw-Hill, London.

Hou, Y., Li, L. and Wang, L (2012). Picking Routes Optimisation of Automated Warehouse Based on Parthenon Genetic Ant Colony Optimisation. International Conference on Convergence Information Technology, Lecture Notes in Information Technology (19), pp. 198-204.

Hsu,C.M.,Chen,K.Y.andChen,M.C. (2005). 'Batching orders in warehouses by minimizing travel distance with genetic algorithms'. Computers in Industry 56 (2), pp.169-178.

Hwang, H. and Kim, D. G. (2005). 'Order-batching heuristics based on cluster analysis in a low-level picker to- part warehousing system'. International Journal of Production Research 43, 17, pp. 3657-3670.

Hwang, H. and Lee, S.B. (1990). 'Travel-time models considering the operating characteristics of the storage and retrieval machine'. International Journal of Production Research 28 (10), pp.779-1789.

Hwang, H., Song, Y.K. and Kim, K.H. (2004). 'The impacts of acceleration/deceleration on travel time models for carousel systems'. Computers and Industrial Engineering 46, pp.253-265.

Jaggi, C. K., Parrek, S., Verma, P. and Sharma, R. (2013). 'Ordering policy for deteriorating items in a two-warehouse environment with partial backlogging'. International Journal of Logistics Systems and Management, Vol. 16, No.1 pp. 16-40.

Jane, C. C., and Laih, Y.W. (2005). 'A clustering algorithm for item assignment in a synchronized zone order picking system'. European Journal of Operational Research, 166, pp. 489–496.

Jane, C.C. (2000). 'Storage location assignment in a distribution center'. International Journal of Physical and Logistics Management 30 (1), pp.55–71.

Jarvis, J. M., and McDowell, E. D. (1991). 'Optimal product layout in an order picking warehouse'. IIE Transactions, 23, pp.93–102.

Jewkes, E., Lee, C. and Vickson. (2004). 'Product location, allocation and server home base location for an order picking line with multiple servers'. Computers & Operations Research 31, pp. 623- 626.

Johnson, M.E. and Meller, R.D. (2002). 'Performance analysis of split-case sorting systems'. Manufacturing & Service Operations Management 4 (4), pp.258–274.

Kanet, J.J., Gonzalo Remirez, R. (1986). 'Optimal stock picking decisions in automated storage retrieval system'. Omega 14(3), pp.239-244.

Keserla, A. and Peters, B. A. (1994). 'Analysis of dual-shuttle automated storage/retrieval systems'. Journal of Manufacturing Systems 13, (6), pp. 424-434.

Kutzelnigg, R. (2011). 'Optimal Allocation of Goods in a Warehouse: Minimizing the Order Picking Costs under real-life Constraints'. 3rd IEEE International Symposium on Logistics and Industrial Informatics, pp. 65-70.

Lam, C.H.Y., Choy, K.L., Ho, G.T.S. and Chung, S.H. (2012). 'A hybrid case-GA-based decision support model for warehouse operation in fulfilling cross-border orders'. Expert systems with Applications 39, pp.7015-7028.

lation analysis of narrow-aisle order selection systems'. In: Proceedings of the 1988 Winter Simulation Conference, pp. 597–602.

Le-Duc, T. and De Koster, R. (2003). 'An approximation for determining the optimal picking batch size for order picker in single aisle warehouses'. Progress in Material Handling Research: 2002, pp. 267–286.

Le-Duc, T. and De Koster, R. (2007). 'Travel time estimation and order batching in a 2-block warehouse'. European Journal of Operational Research 176 (1), pp.374-388

Le-duc, T. and De Koster, R.B.M. (2005). 'Travel distance estimation and storage zone optimisation in a 2-block class-based storage strategy warehouse'. International Journal of Production Research 43, 17, pp.3561-3581.

Linn, R.J. and Xie, X. (1993). 'A simulation analysis of sequencing rules for ASRS in a pull-based assembly facility'. International Journal of Production Research, 31 (10), pp.2367.

Mahajan, S., Rao, B.V. and Peters, B.A. (1998). ‘A retrieval sequencing heuristic for miniload end-of-aisle automated storage/ retrieval systems’. International Journal of Production Research 36 (6), pp.1715–1731.
Malmborg, C.J. (1995). ‘Optimisation of cube-per-order index warehouse layouts with zoning constraints’. International Journal of Production Research 33 (2), pp.465-482.
Malmborg, C.J. and Bhaskaran, K. (1989). ‘On the optimality of the cube per order index for conventional warehouses with dual command cycles’. Material Flow 4, pp.169-75.
Mathirajan, M., Manoj, K. and Ramachandran, V. (2011). ‘A design of distribution network and development of efficient distribution policy’. International Journal of Logistics Systems and Management, Vol. 9, No.1 pp. 108 - 137.
Meller, R.D. (1997). ‘Optimal order-to-lane assignments in an order accumulation/sortation system’. IIE Transactions 29 (4), pp.293–301.
Meller, R.D. and Klote, J.F. (2004). ‘A throughput model for carousel/VLM pods’. IIE Transactions 36 (8), pp.725-41.
Meneghetti, A. and Monti, L. (2013). ‘Sustainable storage assignment and dwell-point policies for automated storage and retrieval systems’. Production planning & control 24, 6, pp. 511-520.
Moeller, K. (2011). ‘Increasing warehouse order picking performance by sequence Optimisation’. Procedia Social and Behavioral Sciences 20, pp.177-85.
Nidhi, M. B. and Anil, B. (2011). ‘A cost optimisation strategy for a single warehouse multi-distributor vehicle routing system in stochastic scenario’. International Journal of Logistics Systems and Management, Vol. 10, No.1 pp.110- 121.
O¨nu¨t, S., Tuzkaya, U. R., Dog ˘ac, B. (2008). ‘A particle swarm optimisation algorithm for the multiple-level warehouse layout design problem’. Computers & Industrial Engineering 54, pp.783–799.
Pan, J, C.H. and Wu, M.H., (2009). ‘Study of storage assignment problem for an order picking linein a pick-and-pass warehousing system’. Computers & Industrial Engineering 57, pp.261-268.
Pan, J. C.H. and Shih, P.H. (2008). ‘Evaluation of the throughput of a multiple-picker order picking system with congestion consideration’. Computers & Industrial Engineering 55, pp.379-89.
Petersen, C. G. and Aase, G. (2004). ‘A comparison of picking, storage, and routing policies in manual order picking’. International Journal of Production Economics, 92, pp.11-19.
Petersen, C.G. (2000). ‘An evaluation of order picking policies for mail order companies’. Production and Operations Management 9 (4), pp.319–335.
Petersen, C.G. (2002). ‘Considerations in order picking zone configuration’. International Journal of Operations & Production Management 27 (7), pp.793–805.
Prasad, P.S.S. and Shankar, C. (2011). ‘Cost optimisation of supply chain networks using Ant Colony Optimisation’. INternational Journal of Logistics Systems and Management, Vol. 9, No.2 pp. 218 - 228.
Ratliff, H.D. and Rosenthal, A.S. (1983). ‘Order picking in a rectangular warehouse: A solvable case of the traveling salesman problem’. Operations Research 31 (3), pp.507-521.
Ronald, J. M., Peter, C. S. and Sunderesh, S. H. (2007). ‘Order oriented slotting: A new assignment strategy for warehouses’. European Journal of Industrial Engineering, 1, pp.301-316.
Roodbergen, K. J. and Vis, I.F.A. (2009). ‘A survey of literature on automated storage and retrieval systems’. European Journal of Operational Research (194), 2. pp 343-62.

Roodbergen, K.J. (2001). Layout and routing methods for warehouses. Ph.D. thesis, RSM Erasmus University, the Netherlands.

Roodbergen, K.J. and De Koster, R. (2001). 'Routing order pickers in a warehouse with a middle aisle'. European Journal of Operational Research, 133 (1), pp. 32-3.

Roodbergen, K.J. and Vis, I.F.A. (2006). 'A model for warehouse layout'. IIE Transactions 38, 799-811.

Rosenwein, M.B. (1996). 'A comparison of heuristics for the problem of batching orders for warehouse selection'. International Journal of Production Research 34 (3), pp.657-664.

Routroy, S. and Kodali, R. (2008). 'Development of decision framework for warehouse decisions in supply chain network'. International Journal of Logistics Systems and Management, Vol. 4, No.2 pp. 207-218.

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G., Mantel, R. and Zijm, W. (2000). 'Warehouse design and control: Framework and literature review'. European Journal of Operational Research 122 (3), pp.515-533.

Rouwenhorst, B., Van den Berg, J.P., Van Hou- tum, G.J., Zijm, W.H.M. 'Performance analysis of a carousel system', in: Proceedings of the 1996 International Material Handling Research Colloquium: Develop- ments in Material Handling Research, The Material Handling Industry of America, Charlotte, NC, 1996, pp. 495-511.

Ruben, R.A. and Jacobs, F.R. (1999). 'Batch construction heuristics and storage assignment strategies for walk/ride and pick systems'. Management Science, 45 (4), pp.575–596.

Rushton, A., Oxley, J. and Croucher, P. (2006). The Handbook of Logistics and Distribution Management, third ed. Kogan Page, London.

Russell, M.L. and Meller, R.D. (2003). 'Cost and throughput modelling of manual and automated order fulfilment systems'. IIE Transactions 35 (7), pp.589–603.

Sarker, B.R., Sabapathy, A., Lal, A.M. and Han, M. (1991). 'The performance evaluation of a double shuttle automated storage retrieval system'. Production Planning & Control 2 (3), pp.207-213.

Seidmann, (1988). 'Intelligent control schemes for automated storage and retrieval systems', International Journal of Production Research 26 (5), pp.931-952.

Shah, B. and Khanzode, V. (in press). 'A Comprehensive Review and Proposed Framework to Design Lean Storage and Handling Systems', International Journal of Advanced Operations Management.

Shah, R. and Ward, P.T. (2003). 'Lean Manufacturing: context, practice bundles, and performance'. Journal of Operations Management 21, pp.129-149.

Sharma, S. and Shah, B. (2015). 'A proposed hybrid storage assignment framework: A case study'. International Journal of Productivity and Performance Management, Vol. 64 No. 6. pp.870 - 892.

Sharp, G., Handelsmann, R., Light, D. and Yeremeyev, A. (1996). 'Productivity and quality impacts of pick-to-light systems', in: Progress in Material Handling Research, The Material Handling Industry of America, Charlotte, NC, pp.513-530.

Shiau, J. Y. and Liao, T.C. (2013). 'Developing an Order Picking Policy for Economical Packing'. IEEE, 387-392.

Shuhua, M. and Yanzhu, H. (2009). 'Research on the Order Picking Optimisation Problem of the automated warehouse'. IEEE.

Sobanski, E.B. (2009). 'Assessing lean warehousing: development and validation of a lean assessment tool'. A Ph.D. dissertation, Oklahoma State University, Oklahoma.

Spee, D. (1996). 'Automated order picking system with horizontal racks, in: Progress in Material Handling Research', The Material Handling Industry of America, Charlotte, NC, pp. 545-550.

Staudt, F. H., Alpan, G., Di Mascolo, M. and Rodriguez, C.M.T. (2015). 'Warehouse performance measurement: a literature review'. International Journal of Production Research, 53 (18), pp. 5524–5544.

Taljanovic, K. and Salihbegovic, A. (2009). 'A New Strategy in Picking From the Forward Pick Locations'. IEEE.

Taljanovic, K., Salihbegovic, A. and Pandzo, A. (2011). 'A New Manual Material Picking Process for High Volume / NonSerialised Small Parts Orders'. IEEE.

Tang, L.C. and Chew, E.P. (1997). 'Order picking systems: batching and storage assignment strategies'. Computer & Industrial Engineering 33 (3), pp.817-820.

Tompkins, J.A., White, J.A., Bozer, Y.A. and Tanchoco, J.M.A. (2003). Facilities Planning, 3rd ed., (Wiley: New Jersey).

Tsai, C.-Y., Liou, J. J. H. and Huang, T. M. (2008). 'Using a multiple-GA method to solve the batch picking problem: considering travel distance and order due time'. International Journal of Production Research, 46 (22), pp. 6533–6555.

Van Den Berg, J.P. (1996). 'Multiple order pick sequencing in a carousel system: A solvable case of the rural postman problem'. Journal of Operational Research Society 47, pp. 1504-1515.

Van den Berg, J.P., Sharp, G.P., Gademann, A.J.R.M.N. and Pochet, Y. (1998). 'Forward-reserve allocation in a warehouse with unit-load replenishments'. European Journal of Operational Research 111, pp.98-13.

Vonolfen, S., Kofler, M., Beham, A. and Affenzeller, M. (2012). 'Optimizing assembly line supply by integrating warehouse picking and forklift routing using stimulation'. Proceedings of the 2012 Winter Simulation Conference.

Wen, U.P. and Chang, D.T. (1988). 'Picking rules for a carousel conveyor in an automated warehouse'. Omega International Journal of Management Science 16 (2), pp.145-51.

Won, J. and Olafsson, S. (2005). 'Joint order batching and order picking in warehouse operations'. International Journal of Production Research 43, (7), pp.1427-442.

Yu, M. and De Koster R. (2007). 'Performance approximation and design of pick-and-pass order picking systems'. ERIM report series reference no. ERS-2007-082-LIS. Available at SSRN:http://ssrn.com/abstract=1069328.

Zhang, Y. and Zhang, Y. (2010). 'Research on the Schedule Algorithm of the Order Picking Optimisation Problem in Bend Aisle Warehouse. Seventh International Conference on Fuzzy Systems and Knowledge Discovery'. IEEE, pp. 299-303.

Zijm, W.H.M. and Van den Berg, J.P. (1999). 'Models for warehouse management: Classification and examples'. International Journal of Production Economics 59, pp.519-28.

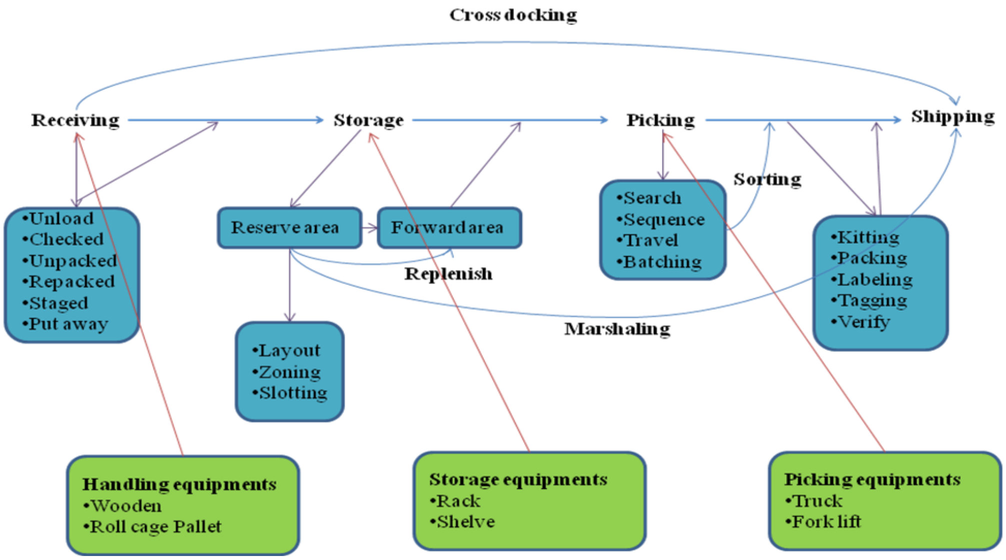

Figure 1. Warehouse operations with basic activities, process flow and equipment

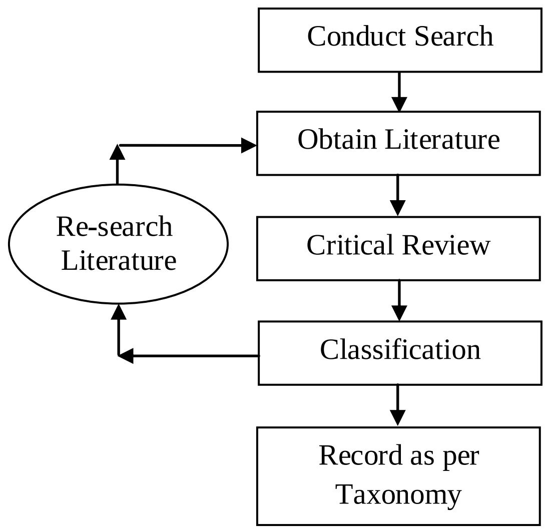

Figure 2. Literature review framework

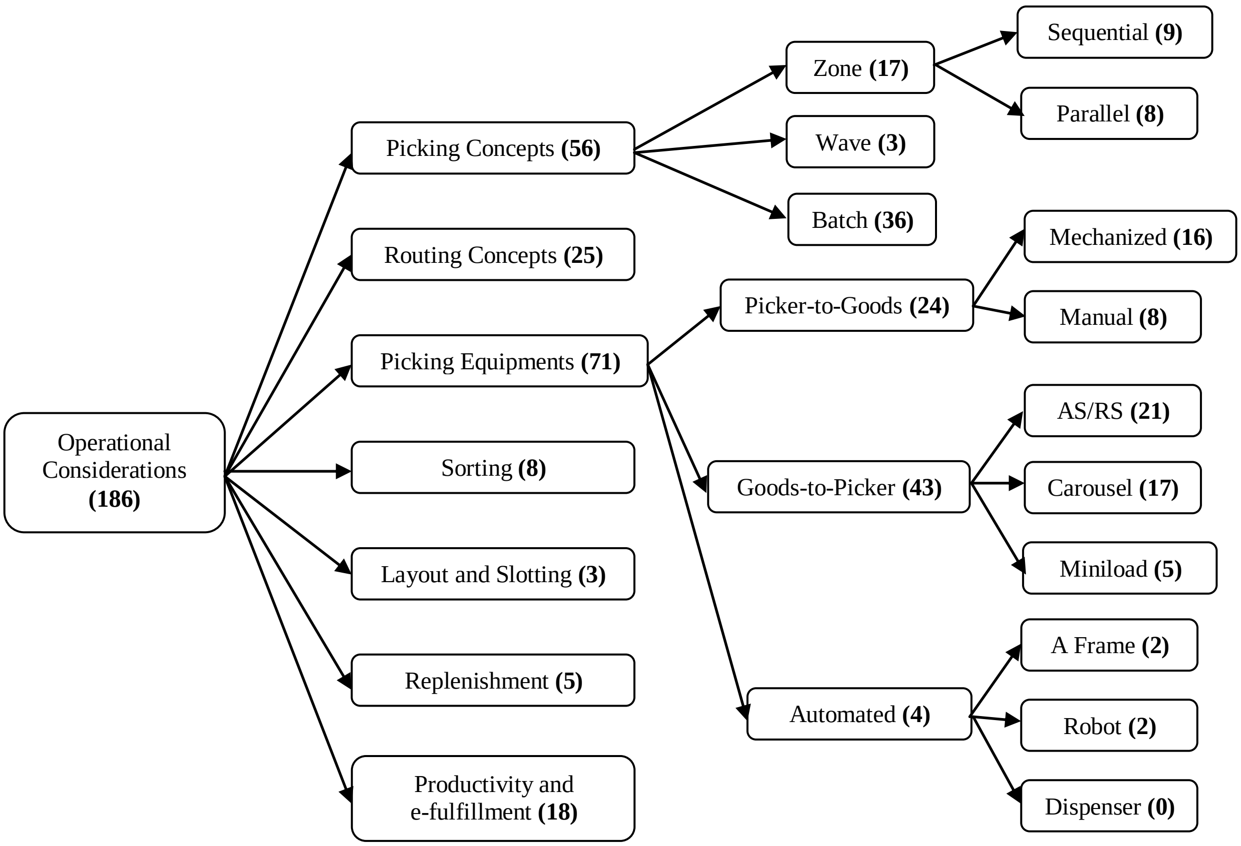

Figure 3. Taxonomy for warehouse operational issues