ISSN: 2321-8169
167 – 171

A Review on Automated Storage/ Retrieval Systems and Shuttle Based Storage/Retrieval Systems

Kalyanaraman, P.
School of Computer Science and Engineering,
VIT University
Vellore – 632014, India
e-mail: pkalyanaraman@vit.ac.in

Keerthika, C*.
School of Computer Science and Engineering,
VIT University
Vellore – 632014, India
e-mail: keerthika.c2014@vit.ac.in

***Abstract*—**Automated storage and retrieval systems are warehousing systems that are used for the storage and retrieval of products in both distribution and production environments. Shuttle based storage/retrieval systems are composed of elevators with lifting tables that are attached on a mast, shuttle carriers, buffer positions and the storage racks. It is observed that the shuttle based storage/retrieval systems increases the throughput capacity of the systems compared to automated storage/retrieval systems. Shuttle based storage/retrieval systems is relatively a new technology in automated storage and retrieval systems and usually works with aisle and tier captive shuttles. This new technology is mostly used for mini-load warehouses. The main body of the paper consists of an overview of literature discussing automated storage/retrieval systems and shuttle based storage/retrieval systems.
Keywords-*Automated storage and retrieval system, Shuttle based storage and retrieval system*

*****

I. INTRODUCTION

An automated storage and retrieval system is defined as a storage system that uses fixed-path storage and retrieval machines running on one or more rails between fixed arrays of storage racks. Automated storage and retrieval systems have been widely used in distribution and production environments. From 1950 onwards, automated storage and retrieval systems have been widely used in warehouses to store and retrieve unit-loads without interference of an operator. The main advantages of automated storage/retrieval systems are savings in labour costs and floor space, increased reliability, and reduced error rates. The main disadvantages are high investment costs, less flexibility, and higher investments in control systems [45]. The early version of an automated storage and retrieval systems is also known as crane based automated storage and retrieval systems which has one storage and retrieval machine in each aisle that cannot leave its designated aisle (aisle-captive system). It can transport only one load at a time. There is large number of system design options for automated storage and retrieval systems in the literature [28, 37].

Shuttle-based compact systems are new automated multi-deep unit-load storage systems with lifts that promise both low operational cost and large volume flexibility. Due to increasingly small order sizes with large product variety and faster deliveries, material handling providers are developing new solutions. To meet this demand in throughput and constraints with regard to delivery times in warehouses, shuttle based storage/retrieval systems are developed in automated material handling industry. This new technology is developed as an alternative to mini-load where it cannot handle the required throughput capacity. In this technology, mostly two elevators lifting tables capable of vertical movement of loads (totes) share a single mast to transport totes from horizontally operating shuttle carriers to input/output locations and vice versa. Shuttle carriers are usually tier-captive, however some other designs with shuttle carriers traveling between tiers and aisles may also be considered.

II. AUTOMATED STORAGE AND RETRIVAL SYSTEMS

In literature review, we can find many techniques of automated retrieval systems that are discussed by many authors. This paper provides an overview of literature from the past 20 years. A comprehensive explanation of the current state of the art in automated retrieval systems design is provided for a range of issues such as system configuration, travel time estimation, storage assignment, dwell point location, and request sequencing. The majority of the reviewed models and solution methods are applicable to static scheduling and design problems only. Requirements for automated retrieval systems are, however, increasingly of a more dynamic nature for which new models will need to be developed to overcome large computation times and finite planning horizons, and to improve system performance.

From the literature survey, we observed that most of the literature addresses design and control problems in static environments. However, in today’s world of rapidly changing customers’ demand, small internet orders, tight delivery schedules, high competition and high service level requirements, it will be increasingly difficult to maintain a good performance when using existing static solution techniques. The research in the field of automated storage and retrieval systems should now move towards developing models, algorithms and heuristics that include the dynamic and stochastic aspects of current business. In this context, one can think of self-adaptive storage assignment methods, online-batching policies and dynamic dwell-point rules. Also algorithms for physical design may need to focus more on robustness of the design than on perfect optimality to ensure that the system will be capable of remaining efficient in yet unknown future situations.

In 1999, Zollinger[45] presented conceptual ideas, useful information, operational conditions, application considerations and appropriate methodology for the analysis when comparing automated retrieval systems with other storage and retrieval methods. The purpose is to provide information that serves to improve the industry's knowledge of storage systems and to bring about an increase in the number of properly applied automated storage/ retrieval systems that utilize in-aisle S/R machines.

General overviews of warehouse design and control include [6,7,13]. Warehouses in supply chain are moving beyond capacity shuttle based storage/retrieval systems technologies towards autonomous vehicle- based storage and retrieval system technologies offering additional flexibility in warehouse operations [9,10]. In this technology, throughput capacity can be varied by changing the number of autonomous vehicles in the system. The main components of an automated storage and retrieval systems are lifts and autonomous vehicles in the rack area. Lifts provide vertical movement for transactions to travel among tiers and autonomous vehicles provide horizontal movement for transaction within the tier. It has to be emphasized that automated storage and retrieval systems is introduced for heavy unit-load transactions [9].

In the literature relatively a lot of papers focus on automated storage and retrieval systems [8-13]. shuttle-based storage and retrieval system is relatively a new technology in automated storage and retrieval systems and usually works with aisle and tier captive shuttles. This new technology is mostly used for mini-load warehouses[37,38]. There are few studies considering this system in the literature. To our knowledge, Sarker and Babu [40] is the only paper discussing exclusively automated storage and retrieval systems, however, this paper only reviews some design aspects of automated storage and retrieval systems while focusing on travel time models.

To insert and extract items from storage is to retrieve systems by machines. It is used to retrieve from multiple categories. Many storage rack assemblies are in the system. Each rack to store has slots inside it to store objects. The rack to store assembly is moved by a storage transport along sides adjacent to any slot. An end to the storage rack assemblies is presented for every rack assembly. At the location of opposite ends of tracks is two conveyor rack assemblies aligned perpendicularly to the track. Conveyor track assemblies provide positional signals according to a transport selection function. A database stores location and information of each object. Mostly queuing models are used to solve the issues in automated storage and retrieval systems [11,12,14].

III. SHUTTLE BASED STORAGE AND RETRIVAL SYSTEMS

Modern warehouses must be able to respond both efficiently and responsively to customer demand with continuously changing assortments. Today response times to dynamic demand are often only a few hours, and demand volumes show enormous fluctuations. Traditional automated unit-load storage systems do not perform well in such contexts, as they are expensive and inflexible in handling fluctuating demand volumes. However, in the last decade, new unit-load storage and retrieval systems that bring both the promise of low operational cost and inherent volume flexibility have emerged. One such technology, recently introduced for unit-load storage and handling, is a shuttle-based compact storage system using lifts instead of cranes.

In general, compact storage systems are popular for storing products with relatively low unit-load demand [7] and are characterized by high space-usage efficiency. They eliminate or reduce the need for travel aisles, leading to smaller, and therefore cheaper, buildings. They can be found in refrigerated warehouses, where minimization of refrigerated space and cooling costs is a prime objective, in distribution warehouses linked to a production site, or in general distribution warehouses as more flexible bulk storage systems feeding to the forward pick areas. Hence, these systems represent an interesting alternative to traditional drive-in or drive-through racks. Several types of compact storage systems have been introduced with different handling systems to allow movements along the x-, y- and z-directions: i) conveyor-based compact storage systems with cranes, ii) shuttle-based compact storage systems with cranes, and iii) very high-density storage systems and live-cube compact storage systems. In the first type, a crane moves simultaneously along vertical and horizontal directions within the cross-aisle, and a conveyor system (i.e., gravity or powered conveyor) provides the depth movement of unit loads. In the second type, shuttles or satellites (which are connected to the crane) instead of conveyors carry out the depth movements of unit loads. De Koster et al. [7] investigated the optimal storage rack design of conveyorbased compact storage systems leading to minimum mean travel time of the storage and retrieval (S/R) machine under the assumption of random storage.

Shuttle based storage and retrieval systems consists of lifting table elevators fixed with a mast, shuttle carriers, position of buffers and the racks to store. The lifting table elevators present vertical way to reach tier in system. Due to increasingly small order sizes with large product variety and faster deliveries, material handling providers are developing new solutions. To meet this demand in throughput and constraints with regard to delivery times in warehouses, shuttle based storage and a retrieval system is developed in automated material handling industry. This new technology is developed as an alternative to mini-load crane based automated storage and retrieval systems where it cannot handle the required throughput capacity. In this technology, mostly two elevators lifting tables capable of vertical movement of loads (totes) share a single mast to transport totes from horizontally operating shuttle carriers to input/output locations and vice versa. Shuttle carriers are usually tier-captive, however some other designs with shuttle carriers traveling between tiers and aisles may also be considered. Warehouses in supply chain are moving beyond crane based automated storage and retrieval systems technologies towards autonomous vehicle-based storage and retrieval system technologies offering additional flexibility in warehouse operations [9,10].

A first study on, shuttle based storage and retrieval systems is completed by Carlo and Vis [3]. They study an , shuttle based storage and retrieval systems developed by the Vanderlande Industries where two non-passing lifting systems are mounted along the rack. In that paper, they focus on the scheduling problem of lifts where two (piecewise linear) functions are introduced to evaluate candidate solutions. They develop an integrated look-ahead heuristic for the solution procedure to improve the total handling time (in terms of throughput). Marchet et al. [29] models an , shuttle based storage and retrieval systems via open queuing network to estimate the performance of the system in terms of utilization of lifts and shuttles as well as waiting times for lifts and queues. To validate the analytical models, they utilize simulation modelling. The developed analytical models demonstrate good estimates for the performance measures. Later, Marchet et al. [30] present main design trade-offs for , shuttle based storage and retrieval systems using simulation. They complete their study for several warehouse design scenarios for tier captive shuttle vehicles.

They present several performance measures from the system – utilizations of lifts and shuttles, average flow time, waiting times as well as cost – for the pre-defined rack designs. Recently, Lerher et al. [21,23] and Lerher [23] have studied , shuttle based storage and retrieval systems by considering energy efficiency concept in the system design. The proposed models provide several warehouse designs and their performances. Designs are considered in terms of velocity profiles of lift and shuttle carriers while performances are considered as amount of energy (electricity) consumption, amount of CO2 oscillation and throughput capacity. These studies provide significant contribution in automated warehouse planning by taking into consideration the environment friendly design concept.

Smew at al. [40] presented a simulation study to trade-off between the conflicting objectives of maximizing customer service level and minimizing Work-In-Process. Bekker [1] proposed as a computationally economic approach to optimize throughout rate and allocated buffer space, which are the two conflicting objectives of the buffer allocation problem. Berlec et al. [2] study the calculation of optimal batch quantity using first the basic model, and then the extended model taking into account the tied-up capital in a production, in addition to the costs of changing the batch and storage costs. They implement the study for a case to find out when either of the two models should be used.

Erkan and Can [8] used analytic hierarchy process and fuzzy analytic hierarchy process) to decide on Barcode or RFID system to select for a company, in order to collect data for its warehouse. As a result of the study, it is found that analytic hierarchy process produces consistent results with fuzzy analytic hierarchy process. Barcode system is selected for the data collection system and fuzzy analytic hierarchy process is found to be more sufficient in decision making process due to its fuzziness and vagueness compared to analytic hierarchy process. Unlike the existing studies, we approach to the, shuttle based storage and retrieval systems from a storage rack design and velocity profiles for shuttle carriers and elevators' lifting tables perspective by using simulation modelling. In shuttle based storage and retrieval systems, there is usually a single shuttle carrier in each tier of the storage rack (tier captive system). This assumption can be released if we use a special shuttle elevator at the back of the storage rack, for moving shuttle carriers up and down to the prescribed tier in the storage rack (tier-to-tier system) [22].

Shuttle-based storage systems with single deep racks, also denoted as autonomous vehicle storage and retrieval systems, have existed for more than a decade and have been successfully implemented at a large number of facilities worldwide. Research contributions on autonomous vehicle storage and retrieval systems technology propose analytical or simulation models to provide travel time expressions, optimize system design, select operating policies, and compare such systems with traditional automated storage and retrieval systems in terms of performance and cost. The most studied application is characterized by multiple tiers of single-deep storage racks where autonomous vehicles perform the horizontal movements along both the storage aisle and the cross-aisle, and one or more lifts are used for the vertical movements. Marchet et al. [29,30] studied a different system configuration adopted for product tote handling. Malmborg [24-28] was the first to study autonomous vehicle storage and retrieval systems performance. He proposed a state equation-based conceptual model of autonomous vehicle storage and retrieval systems to estimate cycle time and vehicle utilization. After this study, a number of papers have proposed analytical models based on a queuing network approach to obtain the system performance and improve the 7 accuracy of the estimates.

Kuo et al.[20] modeled the autonomous vehicles as an M/G/V queue nested within a G/G/L queue to estimate the waiting times for vehicle and lift service. Fukunari and Malmborg[13] adopted a closed network to model an autonomous vehicle storage and retrieval systems, EkrenandHeragu et al. [10-12) showed how the manufacturing performance analyzer (MPA) could be used to study autonomous vehicle storage and retrieval systems performance. Zhang et al. [43] developed an approach to accurately estimate the transaction waiting time. This procedure implies that approximations should be dynamically adjusted based on the variance of the transaction inter arrival times observed in a system. Roy et al. [37] modeled a single-tier of autonomous vehicle storage and retrieval systems using a semi-open queuing network model to allow waiting time estimation. In addition, their study addressed the limitations of previous contributions that provided only initial insights on design configuration by investigating the vehicle assignment rule and the effect of the depth/width ratio and multiple storage zones on system performance.

IV. Conclusion

In both manufacturing and distribution environments, automated storage and retrieval systems are used to store products and to retrieve products from storage in response to production orders or customers' orders. In designing an automated storage and retrieval systems, various physical design problems and control problems need to be solved. Little attention has been paid so far to the relationship between automated storage and retrieval systems and other material handling systems in production or distribution facilities. Especially in situations where the automated storage and retrieval systems is just one of many systems, total warehouse performance cannot be assessed by simply adding up performances of all individual systems. An integrated approach would be desirable and we should develop approaches which simultaneously optimize the design of an automated storage and retrieval systems and another material handling system.

Shuttle-based compact storage systems can be viewed as an extension of the use of autonomous vehicles to compact storage systems. In comparison with well-known automated storage and retrieval systems, shuttle based storage and retrieval systems can substantially increase the throughput capacity of the system. This study is exploit the benefits of shuttle based storage and retrieval systems system design for reducing the mean cycle time of transactions and consequently increasing the throughput capacity of the system. Performance comparison of the studied shuttle based storage and retrieval systems is contrasted with alternative storage rack configurations, velocity profiles of the shuttle carriers and velocity profiles of the elevators' lifting tables in the system. The results from the literature show that shuttle based storage and retrieval systems are effective in reducing the mean cycle time and also show large improvement by increasing throughput capacity.

Acknowledgment

The authors are grateful to the authorities of VIT University, Vellore for the facilities.

References

[1] J.Bekker, Multi-objective buffer space allocation with the cross-entropy method, International Journal of Simulation Modelling, vol. 12(1);2013. pp. 50-61.

[2] T. Berlec, J. Kusar, J Zerovnik, J. and M. Starbek., Optimization of a product batch quantity, Strojniski vestnik – Journal of Mechanical Engineering,, vol.60(1), 2014, pp.35-42.

[3] H.J.Carlo, I.F.A. Vis, Sequencing dynamic storage systems with multiple lifts and shuttles, International Journal of Production Economics, vol.140(2), 2012, pp. 844-853.

[4] A.K.Chincholkar , O.V.Krishnaiah Chetty, G. Kuppuswamy, Analysis of an automated storage and retrieval system using stochastic coloured Petri Nets. Advances in Modelling & Analysis, C , vol. 44(3), 1994, pp. 19-30.

[5] A.K.Chincholkar, O.V.Krishnaiah Chetty, Simultaneous optimisation of control factors in automated storage and retrieval systems and FMS using stochastic coloured Petri nets and the Taguchi method. International Journal of Advanced Manufacturing Technology, vol.12(2), 1996, pp.137—144.

[6] G. Cormier, E.A.Gunn, A review of warehouse models. European Journal of Operational Research, vol.58, 1992, pp. 3-13.

[7] R. De Koster R, T. Le Duc, K.J. Roodbergen, Design and control of warehouse order picking: a literature review, European Journal of Operational Research, vol.182(2),2007, pp. 481-501.

[8] T.E. Erkan and G.F.Can, Selecting the best warehouse data collecting system by using AHP and FAHP methods, Technical Gazette, vol.21(1), 2014, pp 87-93.

[9] B.Y.Ekren, Performance evaluation of AVS/RS under various design scenarios: a case study. The International Journal of Advanced Manufacturing Technology, vol. 55(9-12), 2011, pp.1253-1261.

[10] B.Y.Ekren, S.S.Heragu, Simulation based performance analysis of an autonomous vehicle storage and retrieval system, Simulation Modelling Practice and Theory, vol.19(7), 2011, pp.1640-1650.

[11] B.Y.Ekren, S.S. Heragu, A. Krishnamurthy and C.J. Malmborg,, An approximate solution for semi-open queuing network model of an autonomous vehicle storage and retrieval system, IEEE Transactions on Automation Science and Engineering,, vol.10(1), 2013 ,pp. 205-215.

[12] B.Y.Ekren, S.S. Heragu, A. Krishnamurthy and C.J. Malmborg,, Matrix-geometric solution for semi-open queuing network model of autonomous vehicle storage and retrieval system, Computers & Industrial Engineering, vol.68, 2014, pp.78-86.

[13] M.Fukunari and C.J. Malmborg,, A network queuing approach for evaluation of performance measures in autonomous vehicle storage and retrieval systems, European Journal of Operational Research, vol.193(1), 2009, pp. 152-167.

[14] J.Gu, M.Goetschalckx and L.F.McGinnis, Research on warehouse operation: A comprehensive review , vol.177(1),2007, pp. 1-21.

[15] S.Hsieh, J.S. Hwang and H.C. Chou, A Petri-net-based structure for AS/RS operation modelling. International Journal of Production Research, vol. 36(12), 1998, pp. 3323-3346.

[16] S.Hsieh , and K.C. Tsai, A BOM oriented class-based storage assignment in an automated storage/retrieval system. International Journal of Advanced Manufacturing Technology, vol. 17, 2001, pp. 683-691.

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

[18] Kim J, Seidmann A. A framework for the exact evaluation of expected cycle times in automated storage systems with full-turnover item allocation and random service requests. Computers & Industrial Engineering, vol.18(4), 1990, pp. 601-612.

[19] G.M.Knapp and H.P.Wang, Modeling of automated storage/retrieval systems using Petri nets. Journal of Manufacturing Systems , vol. 11(1), 1992, pp. 20-29.

[20] P.H.Kuo, A. Krishnamurthy and C.J. Malmborg, Performance modelling of autonomous vehicle storage and retrieval systems using class-based storage policies, International Journal of Computer Applications in Technology, vol.31(3-4), 2008, pp.238-248.

[21] T.Lerher, M. Edl and B. Rosi, Energy efficiency model for the mini-load automated storage and retrieval systems, International Journal of Advanced Manufacturing Technology, vol. 70(1-4), 2014, pp. 97-115

[22] T. Lerher, Modern automation in warehousing by using the shuttle-based technology, Arent, D.; Freebush, M. (eds.), Automation Systems of the 21st Century: New Technologies, Applications and Impacts on the Environment & Industrial Processes, Nova Science Publishers, New York, 2013, pp. 51-86

[23] T. Lerher, Y.B.Ekren, Z. Sari and B.Rosi, B, Simulation analysis of shuttle based Storage and retrieval systems, Int j simul model, vol.14(1), 2015, pp. 48-59.

[24] C.J.Malmborg, Interleaving models for the analysis of twin shuttle automated storage and retrieval systems. International Journal of Production Research, vol. 38(18), 2000, pp.4599-4610.

[25] C.J.Malmborg,. Rule of thumb heuristics for configuring storage racks in automated storage and retrieval systems design. International Journal of Production Research, vol. 39(3), 2001,pp. 511-527.

[26] C.J.Malmborg,. Estimating cycle type distributions in multi-shuttle automated storage and retrieval systems. International Journal of Industrial Engineering, vol. 8(2), 2001, pp.150-158.

[27] C.J.Malmborg., Conceptualizing tools for autonomous vehicle storage and retrieval systems, International Journal of Production Research, vol. 40(8), 2002, pp. 1807-1822.

[28] C.J.Malmborg, Interleaving dynamics in autonomous vehicle storage and retrieval systems, International Journal of Production Research, vol.41(5), 2003, pp.1057-1069,

[29] G.Marchet, M.Melacini, S. Perotti and E. Tappia, Analytical model to estimate performances of autonomous vehicle storage and retrieval systems for product totes, International Journal of Production Research, vol. 50(24), 2012, pp. 7134-7148.

[30] G.Marchet, M.Melacini, S. Perotti and E. Tappia, Development of a framework for the design of autonomous vehicle storage and retrieval systems, International Journal of Production Research, vol.51(14), 2013, pp.4365-4387.

[31] B.C. Park., Analytical models and optimal stategies for automated storage/retrieval system operations. PhD thesis, Georgia Institute of Technology, Atlanta, GA; 1991.

[32] B.C. Park., Optimal dwell point policies for automated storage/retrieval systems with dedicated storage. IIE Transactions, vol.31; 1999, pp.1011—1013.

[33] B.C. Park., An optimal dwell point policy for automated storage/retrieval systems with uniformly distributed, rectangular racks. International Journal of Production Research, vol. 39(7), 2001, pp. 1469-1480.

[34] B.C. Park.,, Foley RD, Frazelle EH., Performance of miniload systems with two-class storage. European Journal of Operational Research, vol.170, 2006, pp. 144-155.

[35] B.C. Park., Foley RD,White JA, Frazelle EH., Dual command travel times and miniload system throughput with turnover-based storage. IIE Transactions, vol. 35, 2003, pp. 343-355.

[36] K.J.Roodbergen and I.F.A. Vis, A survey of literature on automated storage and retrieval systems, European Journal of Operational Research, vol.194(2), 2009, pp. 343-362.

[37] **D.**Roy, A. Krishnamurthy, S.S. Heragu and C.J. Malmborg, , Performance analysis and design trade-offs in warehouses with autonomous vehicle technology, IIE Transactions, vol. 44(12), 2012, pp.1045-1060.

[38] **B.**Rouwenhorst, B. Reuter, V. Stockrahm, G.J. Van Houtum, R.J. Mantel and W.H.M.Zijm, Warehouse design and control: framework and literature review. European Journal of Operational Research, vol. 122, 2000, pp.515-533.

[39] **B.R.**Sarker, and P.S. Babu, Travel time models in automated storage/retrieval systems: a critical review. International Journal of Production Economics, vol. 40, 1995, pp. 173-184.

[40] W.Smew, P. Young and J. Geraghty, Supply chain analysis using simulation, Gaussian process modelling and optimisation, International Journal of Simulation Modelling, vol.12(3), 2013, pp. 178-189.

[41] J.P.Van den Berg and A.J.R.M. Gademann, Simulation study of an automated storage/retrieval system. International Journal of Production Research , vol. 38(6), 2000, pp. 1339-1356.

[42] J.P.Van den Berg , Analytic expressions for the optimal dwell point in an automated storage/retrieval system. International Journal of Production Economics, vol. 76;2002, pp. 13-25.

[43] **L.**Zhang,, A. Krishnamurthy, C.J. Malmborg and S.S. Heragu, Variance-based approximations of transaction waiting times in autonomous vehicle storage and retrieval systems, European Journal of Industrial Engineering,, vol.3(2), 2009, pp. 146-168.

[44] H. Zollinger, AS/RS application, benefits and justification in comparison to other storage methods: A white paper, Automated Storage Retrieval Systems Production Section of the Material Handling Industry of America,1999; MHIA Website, from http://www.mhia.org/industrygroups/as-rs/technicalpapers.