IJRAME
ISSN (ONLINE): 2321-3051

INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

A REVIEW ON AUTOMATED STORAGE & RETRAIVAL SYSTEM (ASRS)

Mr. Sagar R. Wankhade[1], Prof. V.A.Kane[2]

[1]*M.I.T. Aurangabad (M.E. Automation),* mr.sagarwankhade@gmail.com

[2] *M.I.T. Aurangabad (Associate Professor),* vijaykanemit@gmail.com

At.Post. Asara Tq- Arni Dist.-Yavatmal(M.S.) Pin-445103 Mob.No.-9096460403
Email- mr.sagarwankhade@gmail.com

Abstract:

In industry most of productive time is consumed in material handling and storage, it is necessary to automate the material handling & storage. Automated storage & retrieval system (ASRS) is one of the technology used to store & retrieve material, tools, consumable products, etc. ASRS have many benefits including savings in productive time, labour costs, improved material flow and inventory control, improved throughput level, high floor-space utilization, increased safety and stock rotation.

This paper summarizes the various components in an automated storage and retrieval system, listing also the benefits of automating a company's storage operation. Details of the various control strategies are included and a summary of the performance measures applied to such systems. This paper takes a review on improving throughput by analyzing storage, retrieval and dwell point strategies.

This paper is specifically concentrate on both a mathematical and a physical model of ASRS based on an industrial locality. This facility will provide capability of testing both mathematically and empirically a variety of ASRS control strategies including: dwell point, travel type, control, continuous or single operation, retrieval, and storage strategies.

Keywords: *Automated storage and retrieval system, ASRS, AGV, Performance analysis of ASRS, Automation.*

1. Introduction

Automated storage and retrieval systems were first introduced in the 1950s to eliminate the walking that accounted for 70 % of manual retrieval time [1]. ASRS have many benefits including savings in labour costs, improved material flow and inventory control, improved throughput level, high floor-space utilization, increased safety and stock rotation.

The efficient operation of ASRS requires planning of

a) Physical storage specifications: height, length, width of storage structure and storage opening,
b) Operating characteristics of AS/R systems: horizontal and vertical velocity, acceleration rate and number of machines and
c) Control strategy.

Typically, ASRS consist of a series of storage aisles each of which is served by a storage and retrieval (S/R) machine or crane. Each aisle is supported by a pickup and delivery (P&D) station typically located at the end of the aisle and accessed by the S/R machine and the external handling system.

Applications of ASRS exist in the assemblies of small electronic components where assembly work-stations are installed in the openings of the storage racks, in clean- room manufacturing environments to reduce the contamination of the products from manual handling, in healthcare distribution centres where pallet loads of medical products, ranging from IV solutions to heart valves are temporarily stored for later distribution. Frozen food processing environments where temperature is always kept at -29°C, making it extremely hostile to human operators represent other implementations of the ASRS.

A recent application of the ASRS is in the automotive industry. After car bodies have been painted, they are moved into storage in an ASRS to coordinate the production schedule with the number of bodies painted a specific colour. The selected bodies are then retrieved and returned to production.

2. Objectives for automating a Company's Storage Operations:

A list of possible objectives that a company may want to achieve by automating its storage operations is shown below [1]:

- To increase storage capacity.
- To increase storage density.
- To recover factory floor space presently used for storing work-in-process.
- To improve security and reduce pilferage.
- To reduce labour cost and/or increase labour productivity in storage operations.
- To improve safety in the storage function.
- To improve control over inventories.
- To improve stock rotation.
- To improve customer service.
- To increase throughput.

3. Components and Operating Features of an ASRS:

Virtually all ASRS consist of the following components: [1]

1. Storage structure
2. S/R machine
3. Storage modules
4. P&D stations
5. Control system

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3.1 Storage Structure:

The storage structure is the rack framework typically made of fabricated steel, which supports the loads contained in the ASRS. This structure must possess sufficient strength and rigidity that it does not deflect significantly due to the loads in storage or other forces on the framework. The individual storage compartments in the structure must be designed to accept and hold the storage modules used to contain the stored materials. The rack structure may also be used to support the roof and siding of the building in which the ASRS resides. Another function of the storage structure is to support the aisle hardware required to align the S/R machines with respect to the storage compartments of the ASRS. This hardware includes guide rails at the top and bottom of the structure as well as end stops and other features required to provide safe operation.

3.2 S/R Machine:

The S/R machine is used to accomplish storage transactions, delivering loads from the input station into storage and retrieving loads from storage and delivering them to the output station. To perform these transactions the S/R machine must be capable of horizontal and vertical travel to align its carriage (which carries the load) with the storage compartment in the rack structure. In many cases the S/R machine consists of a rigid mast on which is mounted a rail system for vertical motion of the carriage.
Wheels are attached at the base of the mast to permit horizontal travel along a rail system that runs the length of the aisle. A parallel rail at the top of the storage structure is used to maintain alignment of the mast and carriage with respect to the rack structure.
The carriage includes a shuttle mechanism to move loads into and from their storage compartments. The design of the shuttle system must also permit loads to be transferred from the S/R machine to the Pick and Deposit (P&D) station or other material handling interface with the ASRS. The carriage and shuttle are positioned and actuated automatically in the usual ASRS. Man-on-board S/R machines are equipped for a human operator to ride on the carriage.

To accomplish the desired motions of the S/R machine, three drive systems are required: horizontal movement of the mast, vertical movement of the carriage and shuttle transfer between the carriage and a storage compartment. Modern S/R machines are available with horizontal speeds up to 200 m/min along the aisle and vertical or lift speeds up to around 50 m/min. These speeds determine the time required for the carriage to travel from the P&D station to a particular location in the storage aisle. Acceleration and deceleration have a more significant impact on travel time over short distances. The shuttle transfer is accomplished by any of several mechanisms, including forks (for pallet loads) and friction devices for flat bottom tote bins.

3.3 Storage Modules:

The storage modules are the unit load containers of the stored material. These include pallets, steel wire baskets and containers, plastic tote bins and special drawers (used in mini-load systems). These modules are generally made to a standard base size that can be handled automatically by the carriage shuttle of the S/R machine. The standard size is also designed to fit in the storage compartments of the rack structure.

3.4 Pick and Deposit Stations:

The pick and deposit station is where loads are transferred into and out of the ASRS. They are generally located at the end of the aisles for access by the external handling system that brings loads to the ASRS and takes loads away. Pickup stations and deposit stations may be located at opposite ends of the storage aisle or combined at the same location. This depends on the origination point of incoming loads and the destination of output loads. A P&D station must be designed to be compatible with both the S/R machine shuttle and the external handling system. Common methods to handle loads at the P&D station include manual load / unload, forklift truck, conveyor (e.g. roller) and AGVs.

3.5 Control System:

The principle ASRS control problem is positioning the S/R machine within an acceptable tolerance at a storage compartment in the rack structure to deposit or retrieve a load. The locations of materials stored in the system must be determined to direct the S/R machine to a particular storage compartment. Within a given aisle in the ASRS each compartment is identified by its horizontal and vertical positions and whether it is on the right side or left side of the aisle. A scheme based on alpha- numeric codes can be used for this purpose. Using this location identification scheme, each unit of material stored in the system can be referenced to a particular location in the aisle. The record of these locations is called the 'item location file'. Each time a storage transaction is completed the transaction must be recorded into the item location file.

Given a specified storage compartment to go to, the S/R machine must be controlled to move to that location and position the shuttle for load transfer. One positioning method uses a counting procedure in which the number of bays and levels are counted in the direction of travel (horizontally and vertically) to determine position. An alternative method is a numerical identification procedure in which each compartment is provided with a reflective target with binary-coded location identifications on its face. Optical scanners are used to read the target and position the shuttle for depositing or retrieving a load.

Computer controls and programmable logic controllers are used to determine the required location and guide the S/R machine to its destination. Computer control permits the physical operation of the ASRS to be integrated with the supporting information and record-keeping system. Storage transactions can be entered in real- time, inventory records can be accurately maintained, system performance can be monitored and communications can be facilitated with other factory computer systems. These automatic controls can be superseded or supplemented by manual controls when required under emergency conditions or for man-on-board operation of the machine.

4. Operation of an ASRS:

An ASRS machine usually operates in one of two modes: single cycle (SC) or dual cycle (DC) also known as interleaving. For each of the modes the S/R machine starts at the P&D station, stores and/or retrieves a load, and returns to the P&D station to complete a cycle. In a SC the S/R machine either stores or retrieves,

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while in a DC it both stores and retrieves in one cycle. In a DC, the S/R machine picks up a load from a P/D station, travels to a storage location to store it, travels to another location to retrieve a load and then returns to the P&D station to deliver it.

According to Han et al (1987) the effectiveness of an ASRS depends on the methods of control that govern the scheduling of storages and retrievals. A common practice in sequencing storage and retrieval requests is that both requests are processed in a first- come-first-served (FCFS) manner. The FCFS assumption is reasonable for storages, since most ASRS are interfaced with a conveyor loop for input and output. In this case, it is difficult to change the sequence of loads presented for storage. However, the FCFS assumption is less compelling for retrievals since retrieval requests are just electronic messages and can be easily re-sequenced. [2]

In a DC, storage and retrieval requests can be paired to decrease the time spent travelling between the storage and retrieval locations. By minimizing the travel time, it is possible to increase system throughput (i.e. the number of storages or retrievals performed per period) and reduce ASRS operating costs such as wear of mechanical parts and electric power cost. Han et al (1987) claim that a 50% or more decrease in the travel-between time component of a dual cycle leads to an increase in throughput of 10-15%. Such an increase in throughput could help to handle peak demand in the operation phase and eliminate an aisle in a multi-aisle system in the design phase, which would lead to considerable savings. [2]

5. ASRS Storage Policies:

In an ASRS empty storage locations are assigned to an incoming pallet in different ways. In random storage assignment, a pallet has an equal chance of being stored in any of the open locations. In a class-based storage assignment the products and storage racks are divided into a number of classes according to the product turnover frequencies. The highest turnover product is stored in the class of storage rack closest to the input / output point (P&D location). A pallet is stored randomly within the class. In dedicated storage each product is assigned to a specific location or set of locations in the storage rack again according to their turnover frequencies.

White and Kinney (1982) noted that in comparison to dedicated storage, random storage generally requires less storage space because the maximum aggregate storage requirement is generally less than the aggregate maximum storage requirements for each product in storage. In comparison to random storage, dedicated storage results in reduced travel time if equal storage areas are assumed. However, since the class-based and dedicated storage policies are based on turnover frequency for each product it is difficult to use them if the turnover frequencies of the products vary with time.

Random storage policy is not affected by varying turnover frequencies. [3]

6. Storage Assignment and Interleaving Rules:

Storage assignment is the selection of an open rack location for the storage of an arriving pallet [4]. Interleaving or Dual Cycle operation allows for the completion of both a store request and a retrieve request on a single trip from the P&D point. That is, upon completion of a store the S/R machine will not return empty to the P&D point for its next instruction; instead the crane will move (interleave) to the location of a retrieve request, make the retrieval and then return to the P&D point. Interleaving systems are also known as dual-address systems, since the S/R machine is capable of visiting two locations (or addresses) between successive returns to the P&D point.

6.1 Storage Assignment Rules:

1. Random storage assignment (RAN): The storage location is chosen randomly from all open rack locations. This rule has been used to approximate the performance of the closest-open-location (COL) rule, a rule widely used in practice.
2. Class-based storage assignment (C2 or C3): The items and the rack locations are ranked according to turnover and distance (in travel time) from the P&D point, respectively. These ranked lists are then partitioned into a small number of matched classes (2 or 3) such that the class of items with the highest turnover is assigned randomly within the class of locations closest to the P&D point, etc.
3. Full turnover-based storage assignment (Full): For this rule the highest turnover item is assigned to the location closest to the P&D point. This rule represents the limit of class-based rules.

Interleaving Rules:

1. No interleaving (NIL): All storage and retrieval requests are initiated with the S/R at the P&D point. These are sometimes referred to as ‘single address’ or single cycle systems because the S/R unit is only capable of visiting a single rack location (address) between successive returns to the P&D point.
2. Mandatory interleaving with FCFS queue discipline of retrieves (MIL/FCFS): A retrieve is performed every time a store is made and the retrieve is chosen FCFS from the retrieve queue.
3. Mandatory interleaving with selection queue of K retrieves (MIL/Q=K): This rule is applicable only when a class-based storage assignment rule is used. Again, a retrieve is performed every time a store is made; however, the retrieve is selected from the first K entries in the retrieve queue. These K retrieves are searched until a retrieve of the same class as the previous store is found. If a retrieve from the same class is not found, the search is repeated using the ‘next best’ class.

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7. ASRS Performance:

The performance of ASRS varies by the definition of the measure and the operating policies adapted [5]. Measures of performance may include:

1. The travel time per storage/retrieval request
2. The total time required to store/retrieve a batch of orders
3. The average waiting time for a storage/retrieval request

Many parameters affect the performance of the ASRS. Although some of the parameters are interrelated, they are divided into three groups: demand requirements, physical design and operating policies.
Demand requirements represent the orders that need to be stored or retrieved to meet the required production (distribution) schedule. The demand may be defined by several parameters:

(i) Number of orders received per unit time.

(ii) The pattern of retrieving the demand as it arrives to the ASRS: A static retrieval pattern implies that when demand arrives it is accumulated into one group and then the storage and retrieval processes are performed on the group until all orders are completed. New arrivals, while a group of storage and retrieval is being processed, form a different group that can be processed after the completion of the current group. A dynamic retrieval pattern implies that a new arrival during the processing of a group is added to the group and re-sequencing and batching of orders is made to accommodate the new arrival(s).

(iii) Number of items to be stored or retrieved per order.

(iv) Weights and sizes of items to be processed.

(v) The due date of the orders.

The second group of parameters that affect the performance of ASRS relate to its physical design. Some of these parameters are: size of storage bins, length and height of storage structure (building the aisle too long may cause the S/R machines to operate at too high a percentage of their capacity), single or double deep rack, and capacity and number of S/R machines.

The third group of parameters that affect the performance of ASRS are the operating policies of the system, which involve rules for storage and retrieval (storage cycle, retrieval cycle, storage and retrieval in the same cycle) of materials, turnover time and item popularity, order sequencing and batching, order retrieval policies (FCFS, LCFS, priority, etc.), order storage policies and routing of the S/R machine.

7. Dwell Point Analysis

The method of determining the point to position the S/R machines when idle is referred to as dwell point policy and the point where the S/R machine is positioned as the dwell point [6].
Egbelu & Wu (1993) also state that in positioning the S/R machine when idle a properly selected dwell point

policy will reduce travel time of the S/R machine in warehouse operation. Several dwell point policies are available. These dwell point rules are derived from simple rules-of-thumb or mathematical programming. Some of these rules are static in nature while others respond dynamically to changes in storage and retrieval demand. Typical dwell point rules include:

1) Dynamically position the S/R machine at a location that minimizes the expected S/R machine travel or response time from the dwell point to the points of need.
2) Dynamically position the S/R machine at a location that minimizes the maximum S/R machine travel or response time from the dwell point to the points of need.
3) Always position the S/R machine at the input station whenever idle.
4) Always position the S/R machine at the output station whenever idle.
5) Always position the S/R machine at the mid-point location in the rack whenever idle.
6) Dynamically position the S/R machine at the last location it visited following the completion of either a single command or dual command cycle.

The dynamic dwell point rules (1 and 2) were proposed by Egbelu (1991). These two rules recognize the dynamic fluctuation in the storage and retrieval demands that are experienced in ASRS from one scheduling period to another. A period may represent an hour, a shift or a day depending on the production schedule of the shop or the distribution centre served by the ASRS. A linear programming model based on location theory was presented by Egbulu (1991) to minimize the service response time in an ASRS through the optimal selection of the dwell point of the S/R machine when idle. For dwell point rule (1) the objective is to minimize the expected travel time or response time of the S/R machine to the location where it is needed, given that the machine originates from the dwell point. For dwell point rule (2) the objective is the minimization of the maximum travel time to the point of need, again assuming that the machine originates from the dwell point.

The dwell point rules (3 – 5) are static in nature and are therefore time, traffic and situation invariant. These rules are mainly concerned with selecting a point along the aisle where the S/R machine should be positioned. In this respect, these rules consider the problem as a one-dimensional location problem. Practically, in an ASRS system, the decision is not only to determine the point along the horizontal guide track to dwell the machine, but also to specify how high the retrieval arm should be positioned. The position of the retrieval arm is important since the time required for the S/R machine to reach a point is determined by the longer of either the horizontal travel time or the vertical travel time. In rules (1) and (2) the S/R dwell point selection problem is viewed as a two-dimensional location problem in which the position of the machine on the linear track and the position of the arm must both be determined simultaneously.

As would be expected, traffic intensity influences the proportion of the time the S/R machine remains idle, and consequently, the frequency with which the dwell point algorithm is invoked. The lower the traffic rate, the higher the frequency of invoking the dwell point algorithm.

The dwell point rule (6), positioning of the S/R machine at the last location visited, does not really respond to the dynamic changes in storage and retrieval demands brought about by the changing production schedule. Rather, it is a function of the sequencing of the storage and retrieval requests made to the ASRS. Traditionally, the dwell point selection uses simple rules-of-thumb (rules (3-6) previously described). These four rules are static in nature as they do not consider the fluctuation in the level of activities in the ASRS from period to period. Egbelu (1991) proposed two dwell point rules that are dynamic in nature. These two rules use linear programming models to dynamically determine the dwell point. [7]

8. Sizing the ASRS Rack Structure

The total storage capacity of one storage aisle depends on how many storage compartments are arranged horizontally and vertically in the aisle [1]. This can be expressed as follows:

Capacity per aisle = $2n_y.n_z$ (1.1)

Where:

n_y = number of load compartments along the length of the aisle

n_z = number of load compartments that make up the height of the aisle

The constant, 2, accounts for the fact that loads are contained on both sides of the aisle.

If a standard size compartment is assumed (to accept a standard size unit load), then the compartment dimensions facing the aisle must be larger than the unit load dimensions.

Let,

x and y = the depth and width dimensions of a unit load (e.g. a standard pallet size) and

z = the height of the unit load. The width, length and height of the rack structure of the ASRS aisle are related to the unit load dimensions and number of compartments as follows:

$W = 3(x + a)$ (1.2)

$L = n_y(y + b)$ (1.3)

$H = n_z(z + c)$ (1.4)

Where:

W, L and H = width, length and height of one aisle of the ASRS rack structure respectively

x, y and z = the dimensions of the unit load

a, b and c = allowances designed into each storage compartment to provide clearance for the unit load and to account for the size of the supporting beams in the rack structure for the case of unit loads contained on standard pallets, Groover (2001) recommends values for the allowances as: a = 150mm, b = 200mm and c = 250mm. For an ASRS with multiple aisles, W is simply multiplied by the number of aisles to obtain the overall width of the storage system. The rack structure is built above floor level by 300 – 600 mm and the length of the ASRS extends beyond the rack structure to provide space for the P&D station.

9. ASRS Throughput

System throughput is defined as the hourly rate of S/R transactions that the automated storage system can perform [1]. A transaction involves depositing a load into storage or retrieving a load from storage. Either one of these transactions alone is accomplished in a single command cycle. A dual command cycle accomplishes both transaction types in one cycle: since this reduces travel time per transaction, throughput is increased by using dual command cycles when the dwell point is specified as other than 'Current' or 'Deposit Point'.

Several methods are available to compute ASRS cycle times to estimate throughput performance. The method presented here is recommended by the Materials Handling Institute as summarized by Groover (2001). It assumes:

a) Randomized storage of loads in the ASRS (i.e. any compartment in the storage aisle is equally likely to be selected for a transaction)
b) Storage compartments are of equal size
c) The P&D station is located at the base and end of the aisle
d) Constant horizontal and vertical speeds of the S/R machine
e) Simultaneous horizontal and vertical travel

For a single command cycle, the load to be entered or retrieved is assumed to be located at the center of the rack structure. Thus, the S/R machine must travel half the length and half the height of the ASRS and it must return the same distance. The single command cycle time can therefore be expressed by:

$$Tcs = 2 * \left\{\frac{0.5L}{Vy}, \frac{0.5H}{Vz}\right\} + 2Tpd$$

$$= Max\left\{\frac{L}{Vy}, \frac{H}{Vz}\right\} + 2Tpd \tag{1.5}$$

Where,

T_{cs} = cycle time of a single command cycle (min/cycle)

L = length of the ASRS rack structure (m)

V_y = velocity of the S/R machine along the length of the ASRS (m/min)

H = height of the rack structure (m)

V_z = velocity of the S/R machine in the vertical direction of the ASRS (m/min)

T_{pd} = pickup and deposit time Two P&D times are required per cycle, representing load transfers to and from the S/R machine.

For a dual command cycle, the S/R machine is assumed to travel to the center of the rack structure to deposit a load and then it travels to ¾ the length and height of the ASRS to retrieve a load. Thus the total distance travelled by the S/R machine is ¾ the length and ¾ the height of the rack structure and back. In this case cycle time is given by:

$$Tcd = 2 * Max\left\{\frac{0.75L}{Vy}, \frac{0.75H}{Vz}\right\} + 4Tpd$$

$$= Max\left\{\frac{1.5L}{Vy}, \frac{1.5H}{Vz}\right\} + 4Tpd$$

(1.6)

Where,

T_{cd} = cycle time for a dual command cycle (min/cycle)

System throughput depends on the relative numbers of single and dual command cycles performed by the system. Let,

R_{cs} = number of single command cycles performed per hour and

R_{cd} = number of dual command cycles per hour at a specified or assumed utilization level.

The equation for the amount of time spent in performing single and dual command cycles each hour is:

$$Rcs.Tcs + Rcd.Tcd = 60U$$

(1.7)

Where,

U = system utilization during the hour

The right hand side of the equation gives the total number of minutes of operation per hour. To solve this equation the relative proportions of R_{cs} and R_{cd} must be determined, or assumptions about these proportions must be made. Then the total hourly rate is given by:

$$Rc = Rcs + Rcd$$

(1.8)

Where,

R_c = total S/R cycle rate (cycles/hr)

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Note that the total number of storage and retrieval transactions per hour will be greater than this value unless $R_{cd} = 0$, since there are two transactions accomplished in each dual command cycle.

Let Rt = the total number of transactions performed per hour; then:

$$Rt = Rcs + 2Rcd \qquad (1.9)$$

10. Conclusion:

This paper summarizes the various components in an automated storage and retrieval system, listing also the benefits of automating a company's storage operation. Details of the various control strategies are included and a summary of the performance measures applied to such systems. The findings from this review are that there is currently a large amount of research on-going with particular emphasis on improving throughput by analyzing storage, retrieval and dwell point strategies.

The best recorded performance was with current dwell point, simultaneous travel, dual control, free-nearest storage and nearest retrieval strategies selected in combination. In general, dual control improved performance (in terms of throughput), simultaneous travel was found to be better than rectilinear travel, dwell point at origin gave very poor results, and a dwell point at current, pick point or deposit point appears best.

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