# BASIC INTRODUCTION

In the late 1990s, several European factories began implementing AVS/RS, taking advantage of the ability of autonomous vehicles in high-density storage systems. AVS/RS features lighter, more flexible vehicles (elevators, space shuttles and satellites). This architecture supports the simulation execution of different activities to improve efficiency and improve stochastic requirements in case. The main differences between AVSRS and AS/RS technologies in system conceptualization include load movement patterns and buffering.

In the AS/R system, the aisle captive storage crane moves simultaneously in one horizontal and one vertical dimension. In the AVS/R system, the vehicle shares a fixed number of lifts that move vertically and horizontally in a two-dimensional space following a rectilinear flow pattern.

Travel patterns in AS/R systems are generally more efficient than those used in AVS/R systems. AVS/R systems have advantages in adaptability of throughput capacity to demand through variation in the number of S/R devices operating in a fixed rack configuration, and the ability to service any storage address using any S/R device in the system.

AS/RSs has been widely discussed in the literature, most of which focus on performance analysis by building cycle time models, while some of the analysis models extend travel distance and machine utilization. In AVS/RS systems, the key to conceptualizing systems is to quantify the effects of motion patterns and the resulting queuing dynamics on cycle time and utilization. Conceptualization is the process of identifying the cost benefits that drive most of the initial system costs at the level of design variables. These variables must correspond to a system configuration file that provides sufficient operational capability.

# DISPATCHING POLICIES

The extent of the throughout advantage associated with twin shuttle S/R machines is also dependent on the **storage policy** used in a system. Storage policy refers to the rules used for assigning stored items to the physical storage positions within a rack.

AS/RS dispatching policies are rules for placement of items in storage and the sequencing of storage and retrieval transactions. Malmborg [propose](javascript:;)d two extreme policies are randomized and dedicated storage in 1995. With certain exceptions, random storage policies tend to have the advantage of lower total space requirements while dedicated storage policies tend offer the advantage of higher throughput capacity. On the other hand, this advantage may be offset in AVSR systems since storage and retrieval transactions paired under a FCFS operating discipline have a high probability of accessing locations on different storage tiers. In this case, the vehicle movement patterns in AVSR systems negate the travel efficiency advantages of dual command cycles.

For a given system profile (storage rack configuration, vehicle fleet size, number of lifts, unit load characteristics, etc), performance differences between AS/RS and AVS/RS differ due to alternative transaction dispatching policies.

**Randomized storage includes**: (Random storage policies are typically used to achieve space savings since they allow different items to share the same space at different times.)

closest open location (Hausman et al. 1976)

shared storage (Goetschalckx and Ratliff 1990)

Last In First Out (LIFO)

First Come First Serve (FCFS) scheduling policy

**Dedicated storage includes**: (Dedicated storage policies are typically used to maximize throughput by locating items based on their S/R demand characteristics)

the cube per order index (Kallina and Lynn 1976)

turnover-based storage (Hausman et al. 1976)

Due to high cost of per rack, random storage policies are mostly used.

# LITERATURES

## Interleaving models for the analysis of twin shuttle automated storage and retrieval systems, C. J. MALMBORG, 2000

**Malmborg pointed that** modeling issues associated with the sequencing of storage and retrieval transactions in ASR systems have focused on the issue of **interleaving**. Interleaving refers to the pairing of storage and retrieval transactions on the same OP work cycle in order to increase system throughput capacity. (DC, SC, QC). Since interleaving involves more efficient load travel patterns, it is normally implemented as an opportunistic process. i.e. dual command transactions are used whenever both a storage and retrieval transaction are pending at the start of a cycle. As a result, the proportion of S/R cycles using dual commands, often denoted as the α parameter, results from a dynamic process that is impacted by the level of transactions demand in a system, i.e. higher transactions demand results in larger transaction queue sizes and more opportunities for interleaving. Pooling queued transactions in a single buffer may enable AVSR systems to achieve higher α values for a given level of utilization.

Twin shuttle ASR systems could be most easily modelled as independent, single aisle systems where each aisle has a single, dedicated S/R machine. Because changes in S/R machine status are dependent on the transactions queue state and therefore, the transactions demand on a system. Each machine can operate in one of eight states including：

SI: system idle

SC: single demand（SC10: single storage transaction, SC01: single retravel transaction）

DC: dual demand

QC: quadruple demand

EDC type E1: two storage transactions and no retrieval transaction,

EDC type E2: two retrieval transactions and no storage transaction,

EDC type E3: two storage transactions and one retrieval transaction,

EDC type E4: two retrieval transactions and one storage transaction.

To model the system, the discrete-event simulation approach was chosen, since transactions between S/R machine states occur as a result of cycle completions or new transaction arrivals and are governed by the transactions queue state. This type of system can be modelled efficiently as a Markov process. We obtain a set of equations describing transactions between transections queue states, and which can be solved for **state probabilities distribution**. These results can be used in conjunction with cycle time models to estimate overall expected cycle time, system throughput and transaction waiting times for alternative parameter combinations.

Conceptualizing tools for autonomous vehicle storage and retrieval systems, C. J. MALMBORG, 2002

A system of state equations is formulated for describing the dynamic behavior of the queue of storage and retrieval transactions in a storage aisle served by twin shuttle storage and retrieval (S/R) machines.

**Malmborg** [**propose**](javascript:;)**d Conceptualizing tools evaluating the performance**.

Crane utilization is modelled as a function of the S/R cycle time.

Where,

expected S/R machine utilization,

total storage transactions demand per hour,

total retrieval transactions demand per hour,

the number of storage aisles in the system, and

the expected S/R cycle time in minutes.

The average S/R cycle time is a function of the number, depth and height of storage aisles as well as crane travel speeds and load transfer times. The utilization model can be easily applied using a spreadsheet where the S/R cycle time and crane utilization are recomputed as the storage rack configuration is varied.

For a given storage policy, an AVSRS resembles an AGVS in that it is designed to meet a material flow demand along a network of locations distributed along two horizontal dimensions. In this case, vehicle travel is rectilinear and along a fixed guide path.

First step in modelling AVSR systems is to define a material flow matrix associated with the level of S/R transactions demand and the corresponding storage policy. The next step in generating material flow volumes between storage positions is to estimate vehicle re-circulation travel flows. Re-circulation movements depend on interleaving and transactions dispatching policies

An efficient cycle time model for autonomous vehicle storage and retrieval systems, M. FUKUNARI and C. J. MALMBORG, 2006

The model is based on an iterative computational scheme exploiting random storage assumptions and queuing model approximation

**An efficient cycle time model for AVS/RS’s using S/R interleaving**

lift and vehicle dwell point assumptions represent two key aspects of cycle time modelling in AVS/R systems, the dwell point assumption for lifts is that they remain at the storage tier where a vehicle is discharged until the next request for vertical movement. Therefore, a vehicle could access different lifts in completing the vertical movement components of the same cycle. Lifts are assigned to requests from vehicles using first-come-first-serve (FCFS) dispatching. Assume thar vehicles return to the load buffer area or ‘I/O’ point following service completion, blocking effects within storage racks are negligible and that the I/O point is located at one corner of the storage rack. Under the assumptions there are four types of SC cycles and five variations of DC cycles that could occur. The lift queuing system is modelled as a separate queuing system nested within the vehicle queuing system. In the proposed cycle time estimation procedure, these two queuing systems are analyzed iteratively until convergence of their performance measures.

The results also indicate that the technology selection decision has a significant impact of the initial costs and an automated S/R system. The problem with the technique is the lack of flexibility imposed by a nested queuing structure that cannot be readily adapted to modeling contributions to cycle times originating outside of the storage rack.

## A network queuing approach for evaluation of performance measures in autonomous vehicle storage and retrieval systems, Miki Fukunari, 2007

Queuing approach to estimate performance using opportunistic interleaving.

The throughput capacity of an AVS/R system for a given rack configuration is proportional to the number of vehicles subject to interference effects. Interference effects in AVS/R systems are associated with vehicles accessing shared lifts and blocking effects within storage aisles. We can use aisle-captive cranes to avoid these problems. To estimate AVS/R system performance, it is necessary to model the influences of the unique design features of AVS/R technology on expected cycle times and vehicle utilization. Under an opportunistic interleaving discipline, relatively more DC cycles characterize busy periods while relatively more SC cycles characterize slack periods. Subsequently, the expected cycle time is a **weighted average** of the DC and SC cycle times and directly influences the key performance measure of vehicle utilization by defining the average amount of vehicle time per transaction served.

Network queuing models can be applied to address the drawbacks of the state equation approach and nested queuing models.

## Travel time models for double-deep automated storage and retrieval systems, T. Lerher, 2009

The proposed models consider the **real operating characteristics** of the storage and retrieval machine and the condition of **rearranging blocking loads** to the nearest free storage location during the retrieval process.

**Double-deep AS/RS** essentially consist of two single-deep SR placed one behind the other, and so TUL are stored in the first or second storage lane of the SR. Each storage lane of the SR is independently accessible, and so any TUL can be stored in any storage lane at any level of the SR.

Hausman et al. (1976) and Graves et al. (1977) have presented travel time models for unit-load AS/RS assuming that the SR is square-in-time (SIT). Gudehus (1973) has considered the impact of the acceleration and deceleration rate on travel times. Oser et al. (1998, 2004) and Ritonja (2003) considered the multi-shuttle and class based storage system for mini-load AS/RS. Sari et al. (2005) have presented the travel-time models for the 3D flow-rack AS/RS. T. Lerher proposed analytical travel time models for unit-load double-deep AS/RS considering the real operating characteristics of the S/R machine.

**Considering the real operating characteristics and specifying certain assumptions, we can establish dynamics equations of Cumulative distribution in x and y directions and expected travel time, and then modify the equations according to rearrangement definition introduced by FEM 9.851 guideline. So we can deduce the modified cycle time of SC cycle and DC cycle.**

## Variance-based approximations of transaction waiting times in autonomous vehicle storage and retrieval systems, Li Zhang, 2009

This paper describes new cycle time models for AVS/RSs that achieve major breakthroughs in the analytical estimation of transaction waiting times. This is accomplished by first developing explicit representations of service time variability under **three-dimensional rectilinear movement assumptions** and **non-Poisson arrival processes**.

## Analytical model to estimate performances of autonomous vehicle storage and retrieval systems for product totes, Gino Marchet, 2011.

This paper also presents an AVS/RS transaction cycle time estimation and analysis model based on layer constraint configuration of open queuing network.

## Travel time models for deep-lane unit-load autonomous vehicle storage and retrieval system (AVS/RS), Riccardo Manzini, 2015

This paper presents a model for determining the driving **distance and time** of single and double command cycles.

# Conclusion

For a given system profile (storage rack configuration, vehicle fleet size, number of lifts, unit load characteristics, etc), performance differences between AS/RS and AVS/RS differ due to alternative transaction dispatching policies.Continued research with regard to S/R **device dwell points, lift locations, storage policy,** and other operating issues seems worthwhile.

The **disadvantage** of the state equation approach which Malmborg proposed in 2002 is **computational.** According to the difference between the proposed analytical travel time models of T. Lerher and the simulation model, small deviations in the range of – 2.82% are noticed. The magnitude of errors which malmborg proposed averages 0.95% for the low demand scenarios and 1.42% for the high demand scenarios. In the terms of error, travel time models of malmborg is more [precise](javascript:;). But T. Lerher's model is more realistic.

The research mostly focus on the cycle time or machine utilization to assess the performance of AVS/RS system, there is no energy consumption models to analyze the sustainability of such systems.

Should we build on these previous achievements and use previous theories for analysis or develop new theoretical models?