

**METHODOLOGICAL FOUNDATIONS FOR DESIGN  
CONCEPTUALIZATION OF AUTONOMOUS VEHICLE  
STORAGE & RETRIEVAL SYSTEMS**

by

Li Zhang

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Examining Committee:

Ananth Krishnamurthy, Thesis Adviser

Charles J. Malmborg, Member

Daniel Berg, Member

Stephen J. Derby, Member

Rensselaer Polytechnic Institute  
Troy, New York

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## **ABSTRACT**

Autonomous vehicle storage and retrieval (AVSR) systems represent a relatively new alternative in unit load (UL) automated storage/retrieval (AS/R) system technology. It was first implemented at several European facilities in the 1990s and introduced to the U.S. in 2000 [43]. Current and potential suppliers of ULS/R automation technologies based on autonomous vehicles face a gap between the advanced state of their hardware and control system technology, and the design conceptualization tools needed to assess the impact of this technology on ULS/R operations. The lack of accurate and computationally efficient analytical tools to model AVSR system performance has been a primary obstacle to the usage of AVSR systems and the widespread automation of ULS/R's.

AVSR systems have complex system dynamics, especially due to lift dynamics. They are also complex in that their performance depends on an interaction between designs in terms of warehouse configurations (rack configuration, design space restrictions) and operational strategies such as storage policies, retrieval sequencing and dwell point policies. The class of queuing models developed through this research captures the complex and unique features of AVS/R operations under certain system conditions. These analytical models provide the estimates of the main AVSR system performance measures such as S/R cycle times, S/R utilization and system throughput rate. Numerical studies indicate that these approaches are accurate and computationally efficient when compared to corresponding simulation results.

The development of specialized queuing models forms the methodological foundations for design conceptualization of AVSR systems. These models provide the evaluation of alternatives needed to narrow the range of candidate system profiles (storage rack configuration, S/R fleet size restriction, unit load characteristics, etc.). Assessment of the performance effectiveness of AVSR systems versus traditional AS/R systems, especially in system costs, is also investigated for given storage system profiles under certain operational strategies. Such comparison between AVSR systems and AS/R systems provides insights for the selection of storage and retrieval device technology, unit load throughput rates, storage capacity and system configuration.

In addition to summarizing the research accomplishments to date, this document also summarizes areas of continuing and future research.