Robot based compact storage and retrieval systems performance in order picking applications

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Abstract

This paper addresses the application of automation in order picking systems. Specifically, Robot based Compact Storage and Retrieval (RCSR) systems are in focus. To increase the understanding of RCSR; the paper´s purpose is to identify the performance aspects of RCSR systems. The methodology includes developing a theoretical framework of performance and design areas from relevant literature and presents a case study from an application of RCSR system in an e-commerce setting. The findings contribute to supporting companies in the decision making of automation in order picking systems, in terms of when and how RCSR systems could be used.

Keywords: Order Picking, Automated Material Handling, Robot Based Compact Storage and Retrieval Systems

Introduction

Warehouses are becoming increasingly automated for different reasons including the growth in e-commerce and the wide diversity of customer demands. Certain types of automated solutions have been used for several decades, such as conveyers, and crane based systems (Marchet et al., 2014). However, the technological development of automation is progressing. Specifically, automation within Order Picking Systems (OPS) is becoming a common practice to lower manual working costs and achieve higher efficiency (Beckschaefer et al., 2017).

It remains difficult to make decisions regarding which type of OPS should be applied based on context, and companies are becoming increasingly interested in evaluating the different automated OPS (Marchet et al., 2014). The literature investigates a number of aspects of automation in OPS, and while some of these automated systems share many characteristics and selection support aspects, the different types of automated OPS have unique performance aspects that need to be known for an effective use and design of the system.

In recent years, Robot based Compact Storage and Retrieval (RCSR) Systems; such as AutoStore, have been introduced. Their application is increasing for many reasons, one of which is the high space utilization they offer, storing items in bins stacked on top of each other and organized in a grid as shown in Figure 1. In this system, robots are used to store, retrieve, and transport bins to work stations by moving at a higher speed on the grid´s top, with earl characteristics of RCSR, and the effect of the design on the performance are barely investigated.

Therefore, to increase the understanding of RCSR systems, and when they are best used, the purpose of this paper is to identify the performance aspects of RCSR systems, considering the context they are applied in.

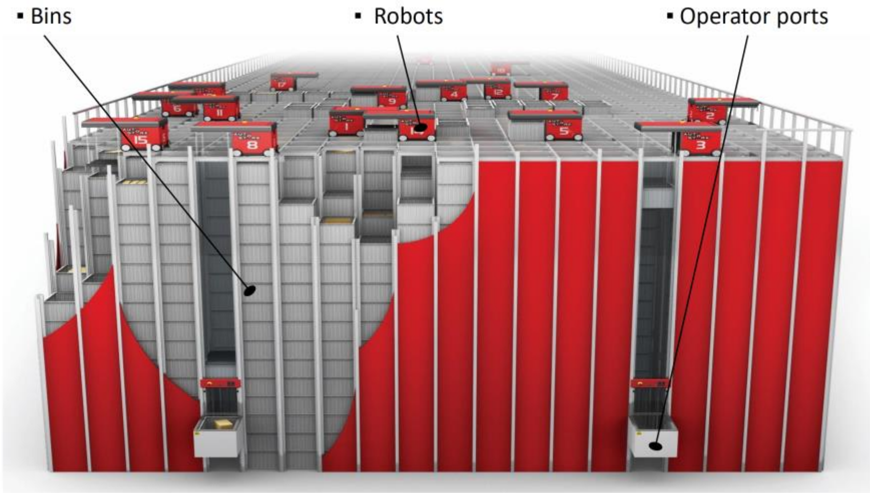

Figure 1 - Layout and components of the RCSR system (Element logic, 2018)

Next, the methodology of the paper is introduced. Thereafter, the theoretical framework is presented based on a review of existing literature on robotic OPS and RCSR systems in specific. The following section includes the case description and the analysis of the paper. Followed by the paper´s discussion, and finally, the conclusions are presented in the last section of the paper.

Methodology

The paper consists of a case study on the implementation and operation of an RCSR system at a third-party logistics provider, which offers warehousing and other logistics services to e-commerce companies. A single case study approach is selected; which is motivated by the lack of knowledge and research in the area, so a case study would allow further understanding of the RCSR systems. The case was selected as it applies the RCSR system in an order picking application which supports fulfilling the paper´s purpose.

Literature review was conducted to find what has been investigated in the robotic OPS, and RCSR system in particular, with focus on the performances of these systems. A framework of performance and design aspects was derived from the reviewed literature, this framework was used for guiding the interviews data collection, and at a later stage was utilized in supporting the analysis of the paper.

A site visit was performed at the case company, with the aim of looking closely at the RCSR system operations and components. Afterwards, further data was collected through a phone interview with the person responsible for the installation and operation of the system at the company, and the performance manager, who has several years of experience working with

RCSR systems. Furthermore, a telephone interview was conducted with the RCSR system´s provider.

The interviews were semi-structured to allow for extended discussions, and additional aspects to be explored. The interviews were recorded using a voice recorder device, and afterwards they were transcribed. To increase the validity, the interviews results and analysis were sent back to the interviewees for verification. In a coming step of the study, interviews will be conducted with the third-party logistics customer, and the operators at the system ports for a more detailed overview of the system´s performance.

Theoretical framework

Automation in OPSs has been the focus of much previous research. One type of automation in OPSs is the robotic order picking such as RCSR. RCSR systems which is the focus of this paper are still lacking in current literature. In this section, a literature review is performed on two levels, the first level includes literature on robotic OPSs in general. The second level presents literature on the RCSR topic in specific, presenting the main focus of the reviewed papers, and the performance areas the papers deal with. The literature review results in a framework of the performance and design aspects mentioned in the literature, which is subsequently used to support the analysis.

Many researchers studied the robotic OPSs, Kimura et al. (2015) prototype a mobile dual arm robots and Automated Guided Vehicles (AGVs) order picking system in a high mix low volume warehouse. Several performance areas are highlighted: The ease of implementation, product orientation errors, and the increased flexibility compared to manual OPS as it can be easily adjusted to changes in product quantity by changing the hardware design, including the number of AGVs, dual or single arm robots, and the number of grippers. A recent review on robotized handling systems is provided by Azadeh et al. (2017) covering systems such as shuttle based storage and retrieval systems, shuttle based compact storage systems, and mobile fulfillment systems.

Several researchers investigated Robotic Mobile Fulfillment Systems (RMFSs), Bauters et al. (2016) develop a simulation model to investigate the performance of an RMFS, where the aspects affecting the system´s throughput are studied. It was found that the number of SKUs per rack, number of AGVs in the system, and the AGVs speed are mainly influencing the system´s throughput. The performance was compared to an Automated Storage and Retrieval System (AS/RS), where the RMFS system achieved higher throughput, and a 10% lower picking station utilization due to the bulk delivery of items to the picking stations in the AS/RS. Boysen et al. (2017) develop an optimized order picking solution for an RMFS focusing on the order processing. The solution leads to more than 50% reduction in the number of used robots in the system. Furthermore, they study the storage policy and suggest storing different stock keeping units (SKUs) in the same pod to reduce the number of robots (Boysen et al., 2017). Lamballais et al. (2017) develop a model for estimating the performance of RMFS, by measuring the throughput, robot utilization, workstation utilization, and the order cycle time. Yuan and Gong (2017) build a queue network model to find the optimal number and velocity of robots for achieving lower throughput time in an RFMS.

On the RCSR in specific; Huang et al. (2015) provide an overview of robotic developments including RCSR, and how they can affect the e-commerce logistics facilities. RCSR can achieve an outstanding performance in terms of storage density and very high flexibility for picking small size items (Huang et al., 2015).

Zou et al. (2016) investigate an RCSR system, and model it as a semi-open queueing network and compare two storage policies (single product type in a stack versus several products in the same stack), and their effect on the system´s performance, they show that having a single product type in a stack results in shorter throughput time. Zou et al. (2016) compare an RCSR to a manual OPS, and find that it has a higher space utilization, and a higher throughput.

Singha et al. (2017) present a paper dealing with the robots software, more in specific; the navigation of autonomous robots in a grid based warehouse, they develop a biologically inspired neural network (BNN) model, in addition to sensor based navigation and mapping algorithm to help the robot reach the target in the grid using a collision free path.

Beckschäfer et al. (2017) study the operational storage policies for RCSR systems using discrete event simulation for a couple of storage scenarios, and their effect on the efficiency and the box space utilization. One policy includes having one type of product per bin, and the second policy includes a bin divider that allows two product types per bin (Beckschäfer et al., 2017).

The reviewed literature on robotic OPS and RCSR systems is used to develop the theoretical framework presented in Table 1. The performance and design aspects dealt with in the literature are categorized into seven relevant performance areas and four different design areas.

Table 1 - Performance and design aspects in robotic OPS framework

Performance areas	Reference	Design areas	Reference
Ease of implementation	Kimura et al. (2015)	OPS equipment	Bauters et al. (2016); Boysen et al. (2017); Yuan and Gong (2017)
Flexibility	Huang et al. (2015); Kimura et al. (2015)	Robots specifications	Kimura et al. (2015)
Efficiency	Lamballais et al. (2017); Yuan and Gong (2017)	Robots software	Singha et al. (2017)
Quality	Kimura et al. (2015)	Storage policy	Beckschäfer et al. (2017); Boysen et al. (2017)
Resource utilization	Lamballais et al. (2017)		
Space utilization	Huang et al. (2015)		
Throughput	Bauters et al. (2016); Lamballais et al. (2017); Zou et al. (2016)		

Case description and analysis

The studied company is a third-party logistics provider who has installed the Autostore system and is currently operating it to one of their customers, the customer is selling a variety of products including tools and machining instruments via e-commerce. The installation of the system in order picking applications was completed in November, 2017 and is currently fully operating the system.

The free storage height of the company´s warehouse is about 11.5 meters, and the ceiling height is around 14 meters. The installed RCRS system consists of 69,000 plastic bins placed in the grid, 52 robots performing the picking of bins and delivering them to operator ports, in addition to 15 working stations; consisting of 10 carrousel ports and 5 inbound ports. Each carrousel port includes a rotating arm within the working desk, where the robot can drop down or collect two bins from the workstation, and the operator has one bin presented at the same time. At the inbound ports, which are also called conveyer ports, the robot can drop down only one bin at a time. The capacity of the system is 1,250 bins presentation per hour. The customer has 40,000 article numbers, where around 85% of these articles goes through the RCSR system.

The remaining 15% of articles are too large or too heavy to fit inside the system bins, furthermore, some items have very small quantities that it is infeasible to store them in the system. The customer has 12,000 order lines per day, the average order has 4.5 order lines, and 4 picks per order line.

Next, the interview results are presented following the seven performance areas in the developed framework in Table 1, while the last performance area which is costs was added after conducting the interviews.

Ease of implementation

The implementation at the company started with an integration between the company control system and the steering system from the RCSR provider. Afterwards, the electronics connection started, followed by installing the electrical devices and preparing the floor space for the system installation. The system provider performed the RCSR system´s installation within a period of seven weeks for the case company.

Regarding the operators training, at the case company a short training was given to the employees at the installation phase of the system by the RCSR provider. The system´s supplier considers the RCSR as an easy to learn and use system. However, the case company pointed out that the operators need a couple of months of working in the system before reaching the set picking targets.

Flexibility

The bins inside the grid cells come in two different heights and materials, enabling different sizes of products to be stored in the system. The maximum weight capacity of the bins in the case company is 30 kg per bin. Furthermore, the system could have a mix of the two bin heights, with the condition of having the same bin height in the top level of the grid.

The scalability of an RCSR system is better than miniload and shuttle based systems; the handling capacity is dependent on the number of robots and operators ports, with no aisles needed for expansion. However, it is more difficult to expand compared to manual OPS, which is dependent on the number of operators. Physical expansion of the system in this case takes around 3 months, where the grid structure can be tailored to support customer needs, and rectangular cells can be configured to different heights and shapes to increase the number of handled parts. Furthermore, robots can be added to the system within three weeks if needed to increase the throughput, the robots installation could take place during operations with no need to stop the system.

Another flexibility aspect is the different picking strategies that can be selected according to the company preferences. Some of the available options by the system provider are: Pick to conveyer, pick to pallet, pick to trolley (batch), and express handling for urgent or special orders.

Efficiency

Both interviewees agreed that RCSR system´s implementation usually results in at least 50% increase in efficiency compared to a manual order picking system, as it allows an increased pick per hour rate, and eliminates operators transportation compared to manual OPS. When it comes to time efficiency, the speed of delivery to the customer was one area highlighted by the system´s supplier, as it allows faster responses to customer orders compared to manual picking systems.

RCSR systems have minimal downtime, according to the interviewees the system has no single point of failure. According to their experience the downtime of an RCSR system could be less than 1%.

Quality
The picking accuracy is very high compared to manual systems, picking errors are reduced dramatically when using RCSR systems. The error rate at the case company is reported to be 0.09% of the order lines, based on customer complaints, occurring mainly due to wrong quantities picked by the operators at the workstations.

Resource utilization
The energy consumption of RCSR could be lower than other picking systems in the same category, according to the system´s supplier. The robots are battery driven, where the battery life would last up to eight hours and requires six hours to fully charge without affecting the system´s performance; as the charging time could be planned to occur at the same time the operators are off work.

Furthermore, RCSR could lead to up to 40% reduction in the used packaging for the items, which have a positive environmental impact. Another highlighted aspect by the case company is the relatively low manning level in RCSR systems, as they are stated to require less operators than manual, miniload and shuttle based OPS.

Space utilization
The system supplier indicated that the RSCR system can result in up to 80% floor space savings compared to manual OPS. Both interviewees confirmed that RCSR systems have the capacity to store more items per square meter compared to manual solutions. The scalability of the system does not necessarily mean more space area is needed, as no aisles are required to expand the system.

Throughput
The throughput of the system is set by the supplier to retrieve 120 to 350 bins per hour at each operator port. However, according to the case company the current throughput is around 65 bins per hour, as the human operators at the ports cannot cope with a throughput exceeding this limit.

Costs
One performance area that emerged through the interviews is the financial performance aspect. The investment cost of an RCSR system is relatively high as indicated by the case company and could reach twice the miniload and shuttle based system investment costs. However, the system expansion costs for an RCSR is less than that for miniload and shuttle based systems, as it has lower equipment costs compared to miniload and shuttle based systems.

One limitation of RCSR according to the case company is that such a system could be ineffective cost wise in situations with a capacity of 4000 to 4500 order lines per hour, or in situations where the frequency of items picking is equal. As for the system to be both cost and time efficient some items should be of lower order frequency so they can be stored at the bottom of the system´s grid.

Discussion
This paper has highlighted several unique performance characteristics where an RCSR system is likely to differ from other picking systems; for example, RCSR systems are relatively easy to expand physically in terms of storage area, and number of bins and robots in the system. Also, RCSR systems offer high space utilization compared to other OPSs. This paper has also mentioned several surrounding context aspects that need to be considered for RCSR systems in general, such as the limitations for the items size and shape to be fitted inside the bins.

The interrelationships between the OPS design, context and their effect on the performance need to be recognized when selecting an appropriate type of automation for order picking. One of the interrelationships between the RCSR design and performance lies between the number of robots and bins in the system and its scalability. Another interrelationship exists between the bin´s weight and resources consumption, more specifically energy consumption; as increasing the bin´s load capacity to a certain extent would cause the robots to consume more energy and could decrease the robots battery life. Furthermore, careful decisions need to be made when designing such a system, for example increasing the number of operator ports does not necessarily result in increased efficiency.

The surrounding contextual aspects could play a major role in the system´s performance, for instance the building ceiling height acts as a constrain to the scalability of the system. And the items order frequency could as well affect the performance of the system, as some stored items should have low order frequencies for a feasible application of the system.

The identified performance areas from the literature were found valid for RCSR systems. In an RCSR; flexibility, efficiency, space and resource utilization seem to be important and unique performance areas compared to fully manual OPS and other types of automation. Costs of RCSR was one area brought up through interviews and was found relevant to include in the analysis of the paper.

The case study included interviews with the system supplier and a case company operating the system, where each of them holds different perspectives and expectations of the system, the two parties statements in the interviews were well aligned, which increases the validity of the paper and reflects a relatively full picture of the system´s performance. Furthermore, the interviews results and analysis were sent back to the interviewees to increase validity and avoid misinterpretation.

Conclusion

This paper has focused on RCSR system in order picking applications, has presented the performance areas highlighted in literature for robotic OPS, and accordingly investigated the performance of RCSR compared to fully manual systems and other types of automation. The paper is based on a case study of the application of RCSR, and thus provides insights into the performance of such a system, and when it is best used. The findings contribute to supporting companies in the decision making of automation in order picking systems, in terms of when and how RCSR systems could be used. Although this paper focuses on RCSR system´s application in a case company; the findings concerning the performance and context aspects for the system could be generalized to other RCSR systems. Furthermore, the paper contributes to the broader area of automation in order picking by providing more understanding on the application of these systems.

Current research on RCSR systems is relatively scarce. Future research is needed to further explore the design and context impact on the performance of RCSR systems. Furthermore, in this paper the RCSR performance was studied in a distribution to customer context, it could be interesting to investigate the RCSR performance in a material supply to manufacturing context.

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