Automated Loading and Unloading Operations: A Systematic Review

Farook Abdullah Sultan[1]*; Robin Hanson[1]; Dan Andersson[1]; Mats Johansson[1]; Tarun Kumar Agrawal[1]; Gunnar Stefansson[1]; Konstantina Katsela[2]; Michael Browne[2]; Sai Rohan Gowtham Kodati[1]

[1] Chalmers University of Technology, 41296 Gothenburg, Sweden
[2]University of Gothenburg, 40530 Gothenburg, Sweden

Correspondence address: sultanab@chalmers.se

Purpose
Material handling has witnessed changes with automations occurring in the transport sector. The increasing implementation of autonomous trucks lays questions on the loading and unloading operations that the conventional truck driver used to perform. Loading and unloading operations interface warehouses and transportation. Conventionally characterised by the manual operating nature causing inefficiencies and discontinuities, automated loading and unloading (ALUL) benefit by enhancing workflows, improves performance, and reduces losses. Despite these benefits, research on ALUL is minimal. This article i) details focus of ALUL systems in research, ii) indicates adopted evaluation indicators and iii) highlights key enablers and impediments witnessed during implementation.

Methodology
Developments are assessed by carrying out a systematic literature review including published literature, technical articles etc. Review is initiated by identifying appropriate keywords, coupled with Boolean operators, to retrieve literature from scientific databases.

Findings
Research on LUL reveal a classified research focus on perception systems, manipulators, and general solution type. Operating time was identified to be a commonly evaluated performance parameter despite research revealing diverse parameters. The review highlights i) variable loading and unloading methods with changing good types. ii) Complexities in identifying and manipulating goods. iii) Frequent human involvement, and iv) high implementation costs and associated infrastructural modifications to influence implementation despite many enablers supporting the implementation of this technology. Despite the above issues, commercial solutions with varied degrees of automation are available and are listed in this article.

Practical implications
ALUL systems are described comprehensively providing a detailed representation of existing knowledge regarding ALUL, making selection easier for interested industries and guiding them through the transformation process.

Originality
Research aids in determining function-specific systems enabling a detailed understanding of ALUL systems.

Keywords: Material handling, Automation, Loading, Unloading, Performance.

1. INTRODUCTION

The augmentation of supply chains with Industry 4.0 concepts has positioned automation as an integral part of supply chains (Kadir et al., 2019). One such echelon that has witnessed this impact is the domain of transport. Transport systems serve the purpose of links acting as an interface between nodes within a network (e.g., suppliers, production facilities and distribution centres). One aspect of automation in the transport sector has been in terms of using autonomous modes vehicles for freight transport. The absence of a driver in case of autonomous operations may benefit the transport to operate beyond restricted hours, reduce operation costs, reduce buffers, and improve material flow (Costello and Suarez, 2015; Talebian and Mishra, 2022). This advancement is projected to enable higher fill rates, better efficient freight transport, reduce overall operation costs, improve overall lead times and supply chain performance providing competitive advantage to the organization (Sternberg and Andersson, 2014).

However, in this whole process of forming linkages with autonomous transports, one overlooked area is the process of loading and unloading (LUL) (Machado-León et al., 2020) . LUL comprises preparing, lifting, positioning, and restraining goods followed by unloading and the reversel of the processes to and from a vehicle. Owing to the manual and repetitive nature of LUL, the process is reliant on handling efficiency, work intensity, personnel safety, and on-site management (Xu et al., 2021). Furthermore, the time-consuming nature of this operation makes the process a bottleneck resulting in costly downtimes, interrupting continuous flows and effecting supply chain operations (Granlund and Wiktorsson, 2014; Landschützer et al., 2018)

LUL conventionally involves the truck driver manually carrying out LUL and securing the goods. This generally involves using one hand for goods manipulation and the other hand for support activities such as for holding, alignment etc in case of loose goods such as boxes (Garabini et al., 2020) or use forklifts/pallet trucks for manually driving pallets inside the trucks. However, the transition towards autonomous transport necessitates automating the LUL process considering the absence of a dedicated driver. Other reasons for automated loading and unloading (ALUL) include the repetitive nature of this task suffering from poor ergonomics and the need for labor willing to work round the clock, incentivizing automation (Azadeh et al., 2019). The nature of LUL being a secondary interface (i.e., between node and transportation system) to a primary interface served by the transportation system (i.e., between two/more nodes) can influence overall performance thereby necessitating consideration. The importance of automating LUL get additionally stressed with the logistics trend radar 6.0 categorising mobile robots for LUL operations to be of high impact with expectations to increase operational performance (Logitics trend radar 6.0, 2023). The application of automation in the field of LUL however has seen limited considering the trend of digitalisation undertaken in modern day logistics (Pfohl et al., 2020; Stoyanov et al., 2016)

Despite LUL being a susceptible candidate for automation, possible reasons for comparatively low levels of LUL automation include wide variations and constraints witnessed in handling goods followed by challenges in selecting appropriate equipment influenced by facility constraints, characteristics of material handled, and operation uncertainty involved (Echelmeyer et al., 2008a; Scholz-Reiter et al., 2008). Dekhne et al. (2019) further states the cause for this limited implementation to be the lack of clarity on which technology type needs to be chosen. This inconclusiveness rises primarily owing to the varied types of loads available and the variability in systems required to handle these load types. Loads are classified into loose loads and palleted loads, with the former comprising of boxes/sacks and latter comprising pallets (McDonald, 2016). Loose loads require manual labour due to the limited capability of labor to handle varying weights, position and dimensions (Garabini et al., 2020). Palleted loads are handled by forklifts or pallet trucks and are characterized with variability existing only in terms of weight. Despite palleted goods being handled by mechanized devices, the existing process takes a downside owing to increasing volumes, reduction of damages, focus on cost reductions, shortage of labours, stringent health and safety legislations (Driest, 2010a).

All the above-mentioned necessitate understanding the prospects of ALUL operations. As a domain requiring additional research, this article purposes to review the concept of ALUL operations considering it to be vital in the transition towards automated freight transport system. The authors target to explore this development by conducting a state-of-the-art literature review and enlist commercial ALUL solutions. As the LUL technology is emerging, it also gets necessary to review performance evaluation factors and factors promoting and inhibiting adoption of these systems. As a remedial, the following research questions (RQs) will be explored:
RQ1: What is the status of research conducted on ALUL as a potential interface between systems?
RQ2: What existing ALUL solutions are relevant and conceivable to enable autonomous, automated and resource-efficient freight transport?

Insights developed would be an initiative for streamlining and automating LUL developments making operation and integration into autonomous transports more robust. Outcomes derived will discuss the current status of research and will be a guideline for researchers, stakeholders, managers and academicians presenting way forward to understand and ease selection of available ALUL technologies.

2. METHODOLOGY

To identify and fulfil the above-mentioned objectives, a systematic literature review is adopted (Denyer and Tranfield, 2009; Xiao and Watson, 2019). The review explores research and technologies on ALUL discussed in literature, performance evaluation parameters and identifies key enabler(s) impediment(s) influencing implementation. To suffice these, methodology categorised into three phases and proposed in Figure 2.1 is adopted. Phase 1 covers literature review, phase 2 identifies available market solutions and phase 3 converges ideals of both phases to provide comprehensive overview of developments. Further explanation is provided below.

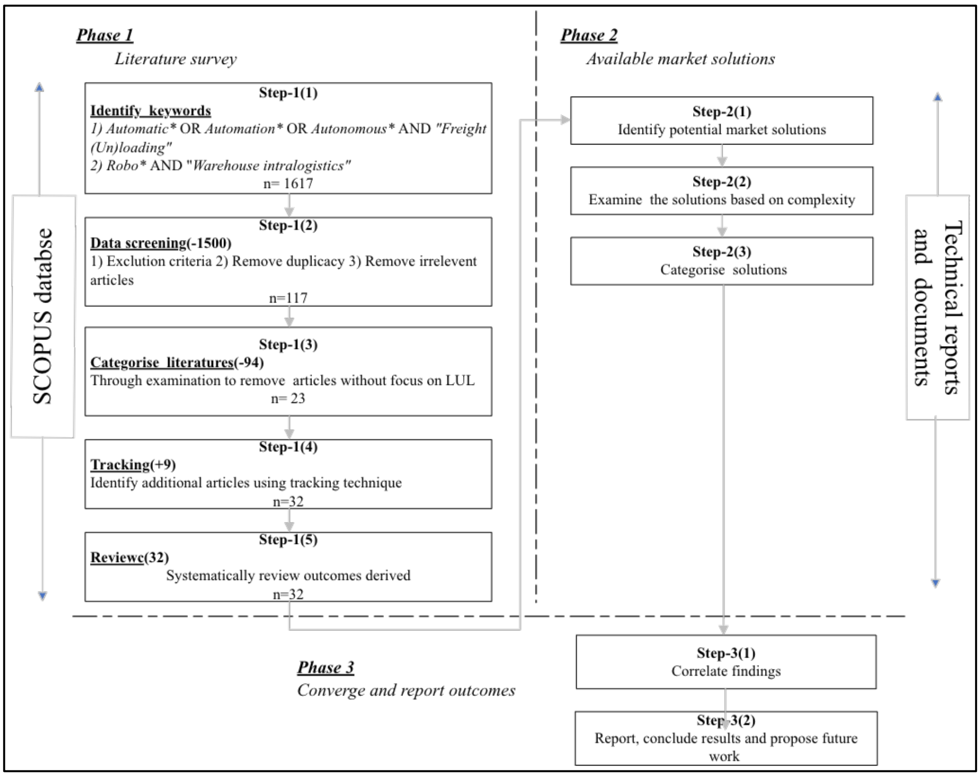

Figure 2.1 Research methodology

Phase 1 commenced with the identification and scrutiny of keywords followed by the gathering of relevant literature using the Scopus database. The scrutiny involved researchers with proficiency in automated material handling comprising of one postdoctoral researcher, one master student and three professors. Initial search revealed 1617 articles which was further subjected to data screening. Data screening involved the application of inclusion criteria that included considering articles published only peer reviewed articles and articles published in the English language. Further screening was carried out with the removal of duplicate articles and articles that lacked focus on LUL in freight logistics. The latter was noticed to be significant as many papers focussed on concepts of LUL other than intralogistics such as loading substrates using robots in laboratories that were irrelevant and were excluded, causing large reductions in articles reviewed. The 23 relevant articles obtained were checked for cross references to identify articles that did not turn out during the initial phase of research increasing the final count to 32 articles. The articles were further subjected to a content analysis using computer-based data extraction forms. This was done to get an insight of the general information regarding publication pattern and other details such as author details, publishing year, journal etc. The discussions dealt are further classified based on technologies studied, performance parameters, enablers, and barriers. Phase 2 involved identifying various LUL solutions available based on their innate features. The outcomes were derived by reviewing market and technical reports. The methodology adopted for phase 2 is adopted from Echelmeyer et al. (2008b) and Gustafsson-Skoglund and Södereng (2012). All outcomes are conjointly assessed to provide an illustration of the ALUL technology stressing upon the factors that need to be considered while selecting these systems. Phase 3 correlated the outcomes revealed from previous phases and presents an insight for future research.

3. RESULTS AND DISCUSSION

Automating LUL is subjected to a multitude of constraints (refer Introduction section). This necessitates in reviewing and detailing the various aspects in which research has been carried out. This also necessitates understanding the important criteria's influencing technology performance (Bamakan et al., 2020) and at the same time understanding the criticalities of implementing these technologies.

To get an overall picture regarding the publication pattern, keywords trend and research focus, a preliminary analysis of the literatures is undertaken (Figure 3.1). Assessments involved analysing the articles retrieved post screening. Year wise assessments reveal an increase in number of articles post 2012 and its steady rise post 2014 (Figure 3.1a). This can be owing to the introduction of industry 4.0 concepts in 2011 (Radivojević and Milosavljević, 2019) and its impactful influence since 2014 (Lasi et al., 2014). This rise also indicates an increased interest towards digital transformation among all facets of industry functioning including logistics (Winkelhaus and Grosse, 2020). Preliminary analysis also indicate that research by Cosma et al. (2004) and Echelmeyer et al. (2008) have acted as a base literature for numerous researches focussing on the topic of ALUL systems. Source wise assessment (Figure 3.1b) reveals a dominant share from conference papers (49.7%) and conference review proceedings (4.5%) in total constituting 53.9% with significant contribution from IEEE proceedings. Journal sources constitute 40.6% of the total distribution chart. Figure 3.1c indicates the links existing between keywords adopted and depicts the relatedness of items in which the terms are found to occur together. This linkage is made considering the keywords sourced from title, abstract, research text and author/index keywords (Sultan et al., 2022). This enables a reader to identify the amount of focus laid by researchers on a topic among the assessed literatures exhibiting an overview of the keywords focused. The illustration also enables in understanding the latest trend of keyword usage along with their frequency and average year of occurrence. A keyword cloud illustrates the frequency of keywords used with large sized keywords representing popular terms (Figure 3.1 d).

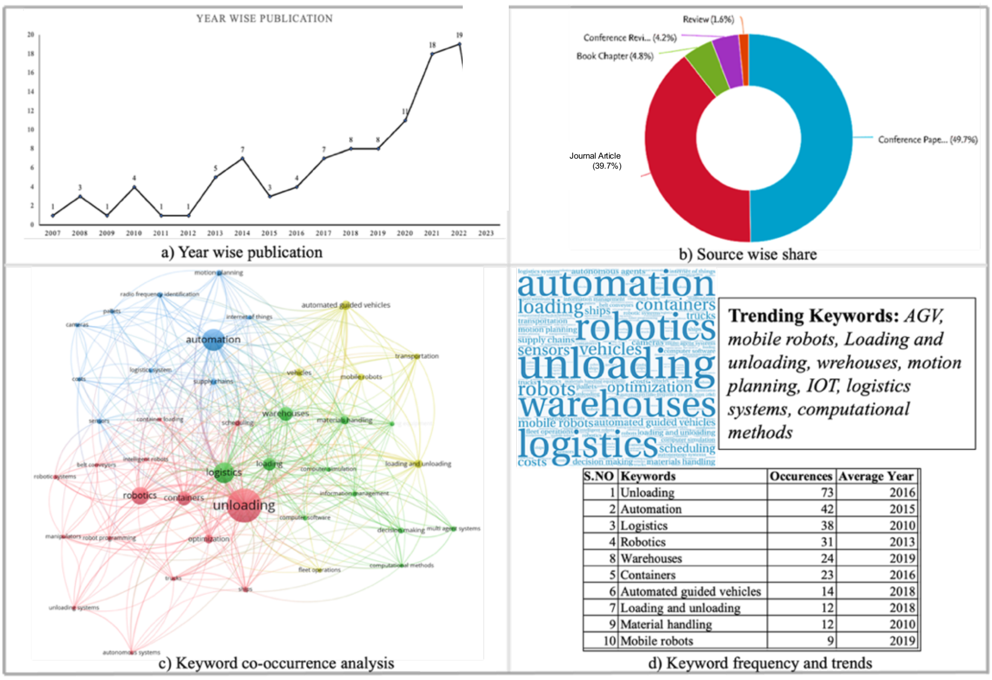

Figure 3.1 Preliminary analysis of selected literature

3.1 Classification of Literature

The retrieved articles are initially categorised based on the type of research methodology adopted based on the works by (Hainey et al., 2016). The types of research found were general studies (11), simulation studies (11), conceptual studies (7), system design (5), case studies (2), analytical studies (2) and review (1) (Table 3.1). However, the major purpose of categorisation apart from providing outlined insights regarding distribution of research is also to give a picture of critical problems. The classification denotes meagre number of case studies and reviews indicating limited implementation status of the ALUL technologies. The limited focus of research entails a dedicated review on the developments of LUL summarising the current state of knowledge. This is carried by elaborating the various dimensions research has reviewed the topic of LUL.

Table 3.1: Methodology based categorization of literature.

Focus type	Focus	Reference(s)
General	• Robots in logistics • LUL in containers • Autonomous systems in logistics • Autopmated and robotic warehouses • Freight management	Echelmeyer et al. (2008b); Kamagaew et al. (2011); Gustafsson-Skoglund and Södereng (2012); Krug et al. (2016); Szymonik (2016); Stoyanov et al. (2016); de Koster (2018); Bodenhagen et al. (2019); Bharadwaj (2020); Sindi and Woodman (2021); Shamout et al. (2022)
Simulation	• Kinematic system • Perception based manupulation system • Algorithm for container loading • Perception and localisation • 3D vision system • Load assignment problem • Grasp evaluation • Deep learning	Echelmeyer et al. (2014); Doliotis et al. (2016); Vaskevicius et al. (2017); Stavrou et al. (2018); Silvestri et al. (2019); Monica et al. (2020); Rjeb et al. (2021); Kharitonov et al. (2021); Chaikovskaia et al. (2021); de Jesús Ochoa- Olán et al. (2021); Gou et al. (2022)
Conceptual	• Mobile manupulator system • Kinematic system • AGV material transfer system • Self capable LUL system • Customised conveyor systems • System compatabile for multiple materials LUL	Bharadwaj (2020); Cosma et al. (2004); Scholz-Reiter et al. (2008); Jaiganesh et al. (2014); Muscolo et al. (2015); Eichberger et al. (2018); Xu et al. (2021)
System design	• Integrated LUL system • Dual arm robot • Smart forklift • System for multiple material typeLUL	Cao and Dou, (2021); Garabini et al. (2020); Gou et al. (2022); Molfino et al. (2015); Muscolo et al. (2015);
Case studies	• Understand influence of (un-named) Semi autonomous loading and supply chain nmetwroks on cost • Container unloading at a coffee warehouse	Cooper et al. (2014); Vaskevicius et al. (2017)
Analytical	• Manupulation system • Dual robot arm	Doliotis et al. (2016); Garabini et al. (2020)
Review		Sindi and Woodman (2021)
Total count		39 (i.e. Articles reviewed (32) + Articles under dual categories (7))

3.2 Systematic Review

Automation has become the modern technological diaspora in intralogistics with trends depicting a positive transition towards automation in all phases of intralogistics. A McKinsey report from 2019 (Dekhne et al., 2019) states the adoption of automation to be non-uniform with less focus on the process of loading and unloading (LUL) of goods in trucks. Despite loading and unloading of palleted goods being carried out by forklifts or pallet trucks, this also takes a downside owing to increasing volumes, reduction of damages, focus on cost reductions, shortage of labours, stringent health and safety legislations (Driest, 2010).

Review of literature reveal a diversified focus of research on ALUL systems with research identified to be done in fields of: i) Perception systems ii) Gripper/manipulation systems iii) Solution types, iv) System performance evaluations, v) Enablers and barriers. This classification also structures to create a view of what ALUL systems contain. Perception systems in general are used for the identification and recognition of parcels for ALUL operations. Gripping systems hold and manipulate the parcel and the solution takes the inputs from the former systems and execute the LUL operation. However, depending on the complexity of the system adopted, the involvements of the perception and manipulation system varies. A fully autonomous system might have the comprehensive involvement of all systems mentioned whereas a more manual LUL system might involve the evasion of the perception and manipulation systems due to the involvement of manual labour with the solution type responsible for picking and placing the parcels. Despite technical focus, evaluating the performance of proposed systems and considering factors promoting and inhibiting adoption also prove necessary (Azzopardi and Nash, 2013). These have been termed factors influencing performance in the discussions. These have been discussed in detail in the upcoming sections and an outline of the factors considered in literature has been represented in Figure 3.2 and have been detailed in the upcoming sections.

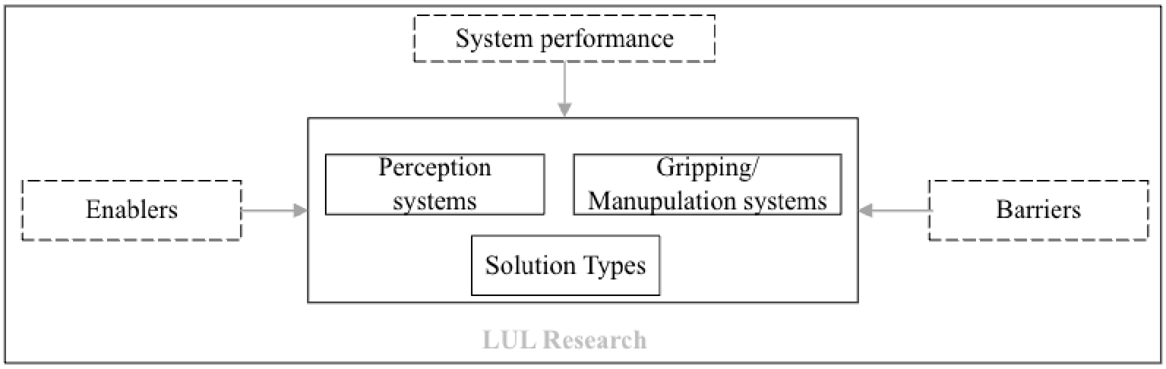

Figure 3.2 Research focus identified from literature

3.2.1. Perception systems

Perception systems aid in identifying loads and carry out LUL accordingly. The term perception relates to the ability of the system to perceive, comprehend and reason about the surrounding environment. This comprises the ability of the system to detect obstacles, recognise objects, 3D environment representation, decision making, planning and operating accordingly in the real world (Premebida et al., 2018).

Landschützer et al. (2018) stated that one of the major issues for unloading is finding the exact behaviour of parcels within trucks. This makes it necessary to understand the knowledge gap existing between the parcels and parcel handling device about parcel variability. A simple way of achieving this according to the author are using RFID tags. Doliotis et al. (2016) conducted a similar initiative to locate and unload regular parcel sizes for autonomous manipulation system combined with 3D vision processing algorithm. The uniqueness of this model was the no prior knowledge of the system required before the unloading process. Though the problem of perception is an accounted problem, the linking of the outcomes from perception system with the grasping technology and its usage for associated motion planning of the system is however limited. Stoyanov et al. (2016) integrated an existent device called Copal with the developed solution modified with customized grippers on a coffee industry. The study revealed such a visualize-think and perform framework increased grasp acquisition lead times and was subjected to failures during grasping trajectories. A similar study was performed by Vaskevicius et al. (2017) with the exception of using RGBD sensors (Red, Green, Blue Depth data sensors) for object recognition in noisy conditions. The study used the Empticon solution for integration and assessing the sensors (Refer Echelmeyer et al. (2014) for detailed information). Adding to the identification problem, Monica et al. (2020) proposed a 3D time of flight sensor for detecting parcel boxes of known sizes. The performance of the system was eventually assessed based on the number of boxes identified and the time taken to identify by the sensor. A novel addition in understanding both loading and unloading operations of carton boxes in trucks was carried out by Gou et al. (2022). This involved the use of novel image synthesis method to acquire data and be able to autonomously recognize box patterns and carry out LUL operations.

When considering pallets, despite the concept of material handling being comparatively less complex comprising forks as manipulators, the problem has been the identification of pallets. To overcome these issue, researchers suggest the incorporation of sensors, lidars and cameras with to predict the range and position details of the pallet and calculate the localization of the pallet. (Bostelman et al., 2006; Wang et al., 2016) used safety sensors and panner sensor coupled with a sensor processing algorithm to automate LUL operations. (Park et al., 2011) presented a vision sensor-based setup with image processing control algorithms for unmanned LUL operation.. (Seelinger and Yoder, 2005) suggested the use of a vison guided control method using mobile camera space manipulation enabling a forklift to engage pallets based on the pallets position using a feedback vision from sensors. Most of the research using vision systems use ficudials to identify the lines and end corners of the pallets (Lecking et al., 2006). This mode of pallet recognition poses practical issues in real time applications considering the availability of adhesive reflectors (ficudials) on all pallets which is difficult in real working conditions. An alternative technique using object recognition using computer aided design negating ficudials was ventured by (Kelly et al., 2007). (Varga et al., 2015) proposed using a stereo camera system to provide information regarding the accurate positions of the pallets. (Walter et al., 2015) proposed the use of coupled perception and vison-based algorithms using single laser scans to detect, engage and disengage forks with pallets. (Wang et al., 2016) suggested vision approach using line structured light using hessian matric decomposition technique capable to handle in unstructured environments. Recent research by (Iinuma et al., 2021) suggested using RGB depth camera for identifying the position of the pallets using semantic segmentation posing capability to handle pallets in inclined positions. Though all the above me tioned process required long processing times, (Li et al., 2021) who coupled the images obtained from the RGB depth camera and used an pallet identification and localisation algorithm coupled with a deep neural network improving recognition speed and accuracy.

3.2.2. Gripper/manipulation systems

The ability of the device to pick and hold objects are served by grippers (Universal Robots, 2022). These play vital roles both when the loads are loose or palleted. Loose goods are generally handled by gripper manipulators. One of the earliest research on the use of grippers in LUL was on highlighting the design of manipulators for indoor logistics in the pharmaceutical industry (Cosma et al., 2004). Despite highlighting key technologies, outcomes stated the main limitations ion such systems used for intralogistics operations were the design of the systems designed for partially structured environments posing incapability to handle dynamic environments characterised by moving forklifts, fallen objects etc. As a development, Scholz-Reiter et al. (2008) assessed the development of suitable kinematics for the courier and packaging industry for handling the variation in goods and recognising piles for effectual LUL operations. The study brought an interesting classification of automated systems based on flexibility, environment restrictions and variety of objects handled. These factors have been a focus of research in LUL for the last 15 years. Robotic grippers used also have an issue owing to the limited dexterity causing underperformance when compared to the human hand (Bodenhagen et al., 2019). The research also pointed out the fact that most research on gripping systems generally avoid the normal way in which the human hand performs grasping that generally involves a reduced or collision free end effector pose, flexibility in reaching goods during tight packed scenarios and ability to sense the object type and handle accordingly. Research by Garabini et al. (2020) primarily focused on the design of grippers as the author felt apart from the perception problem, a major problem to be discussed was the gripping issue. This involved the design of two 7-DOF manipulators for the purpose and end effectors for the purpose to similitude the performance of the human hand. Kharitonov et al. (2021) adopted to venture into a similar problem of evaluating robotic grasps using machine learning and convolutional neural network techniques for unloading operations.

In case of pallets, (Bostelman et al., 2006) states that when a manipulator comes in contact with a pallet, factors such as skew angle, left corner width, height and depth are noted. And when inside a truck, factors such distance between the walls and pallet rows are noted. Further additions were made by (Xiao et al., 2017) who stated the importance of 3 dimensional position, yaw angle pitch angle and role angle when the forklifts are in contact with the pallets. All these factors hold important considering operator mistakes caused due to low accuracy and precision while handling pallets.

3.2.3. Solution types

The conjoint function of the perception system and the manipulator system provides the end solution type. Echelmeyer et al. (2008a) was the first research article to highlight parcel robot, a solution for unloading operations. The research stressed the need for dynamic load planning by sensors prior loading operations. As a development, a much elaborated version citing available developments for LUL operations were mentioned by Gustafsson-Skoglund and Södereng (2012) in their master thesis. This includes commercialised solutions such as Parcelbot, Parcelift, Empticon, Copal systems etc. This also however was the first research to focus on the performance parameters considered while assessing LUL systems. The dimensions assessed included productivity, cycle time, cost effectiveness, ergonomics, feasibility, safety and applicability. Despite the above-mentioned solutions being a respite, the major issue of handling multiple types of goods was still a gap. Though the above solutions were capable in improving LUL rates, the incapability to handle varying types of loads hampered their usage in complex environments. Various kinematic solution for such cases were proposed by Echelmeyer et al. (2014) and simulated on the Parcel robot. A similar study for handling multiple material types (palleted, no palleted and loose materials of irregular shape) both for loading and unloading operations in a tobacco industry was made by Xu et al. (2021). Their study adopted the concepts of using automatic truck loading system (ATLS) capable of handling. Material identification was done using RFID and integrated into the WMS for process recognition. Though a large share of research still focused on loose goods, the amount of research focusing on palleted goods is actually numbered. Cao and Dou, (2021) described the transformation of smart forklifts using PID algorithm. The proposed outcome of this research was the design of an unmanned forklift able to stack pallets side by side. This system could carry out both loading and unloading operations.

Outcomes of the review primarily attempt to understand the problems evident in the design of ALUL system with varied level of success. However, focus/research on commercialized solutions available have been limited. Table 3.2 provides an insight into the commercialized solutions identified. The review does not detail the working prospects in detail and restricts itself in highlighting their performance parameters. A detailed information of some of the mentioned technologies could be gained from Echelmeyer et al. (2014).

Table 3.2 Available LUL solutions

Solution	**Providers**	**Operation**	**Goods handled**	**Design**	**Claimed performance**	**Reference**
Manual	NA	MLUL	Loose goods	• Involves manual labour • Time consuming	30 min-1 hr	
Conveyor belts	Numerous	MLUL	Boxes and pallets	• Consists two or more pulleys with closed loop belt for transferring parcels/pallets. • Operation mostly manual.	-	-
Telescopic conveyor system	Numerous	MLUL	Mainly boxes, containers, small pallets up to 50 kg.	• Extendable conveyor. • Operation mostly still manual.	-	
Dedicated forklifts	Numerous	MLUL	Pallets	• Mechanised device to carry heavy loads. • Manual operation.	1 hour	(Remi-Omosowon, 2017)
Vacuum devices	Vaculex parcelift	MLUL	Only parcels and sacks	• Vacuum suction pipes-telescopic mounted conveyor belt for lifting loads • Cannot handle heavy parcels. • Involves frequent bending for identifying loads.	40 kg lifting capacity	(TAWI, 2019)
Forklift modernisation via attachments		MLUL	Pallets	• Extended forklifts attachments	10-30 tons based on attachment type	(Mannheimer and Josefsson, 2020)
Empticon	Univeyor/ Vollers Hamburg GmbH	Semi- AUL	Loose goods	• Contains vaccuum grippers for holding objects and conveyor belts. • Parcel should have planar surfaces	600 cartons /hour	(Aldoma et al., 2012)
Parcel robot	DHL	AUL	Loose goods	• Telescopic conveyor belt, 3D laser scanner, interchangeable gripping system with articulated arm and grabber. • Parcel should have planar surfaces	500 parcels /hour	(ROBOTICS, 2016; Scholz-Reiter et al., 2008)
Automatic Truck Loading System (ATLS)	Ancra systems/Jorolda	Semi- AUL	Bulk products such as pallets	• Automatic system for insertion and removal of pallets into truck with minimal operator intervention.	10 min/truck	(Driest, 2010b; Piasecki, 2003)

				• Bulk products		
Mobile container unloading system	Copal C2	Semi-AUL	Loose stacked boxes and bags	• Contains Mobile conveyor system with vacuum grippers	100 kg/lift (800 pcs/hr) or 380 sacks/hr	(Copal C2, 2022)
Articulated arm loader/unloader	HONEY WELL	AUL	Loose stacked boxes	• Vehicle-mounted articulated arm comprising vacuum suction device and conveyor system.	Unloading- 1500 CPH	(Honeywell Intelligrated, 2019)
Robotic unloaders with vacuum arm and sweep system	Daifuku RTU/RTL /Stretch	ALAU	Loose stacked boxes	• Vacuum suction arms with conveyor system	Loading rate- 1000CPH//unloading rate- 900CPH	(Daifuku, 2016)
Autonomous forklifts/AMR	Navflex/ Gideon/ Visionnav /JBT	ALAU	Pallets	• Ability to navigate using SLAM as decision making system.	-	(DB Schenker, 2022)

Note: MLUL-Manual loading and unloading, AUL- Autonomous unloading

3.2.4. Factors Influencing Performance

This section details the various factors that influence performance covering system performance enablers and barriers. Performance evaluations play an important role for the design selection and operation. for benchmarking required performances and also aid in selecting the most appropriate solution. Key performance indicators (KPIs) quantify system performance and specify the performance level required. In automated loading/unloading operations, the critical KPIs required to be assessed involve throughput, workload, system availability and mean time to repair, mean time between failures, and error statistics (Raith et al., 2021). Bostelman et al. (2016) laid importance on time duration, repeatability, accuracy, task completion/effectiveness, efficiency, dexterity, autonomy and stability to measure performance. Other methods of performance evaluation involved research by Burdzik et al. (2014) who assessed performance using total handling time performance index calculated by taking a ratio between time for load/unload and total duration of transport. Kreuzer (2021) suggested measurement of performance to be based on the number of cartons/goods handled per unit time. Echelmeyer et al., (2011) stated the factors influencing adoption of automation in logistics to be economic efficiency, system performance, system flexibility, process quality and ergonomics, with the former two only being quantifiable.

Though it might be evident that certain performance seems inclusive of all ideals that need to be considered, some articles seem conclusive in deciding which parameters need to be highlighted. Larger share of concentration tends to focus on time, workload, cost, reliability and perception. However, we feel that in overall, to understand the impact of implementation changes, the performance parameters adopted must in general comprise of the aspects of i) Cost, ii) Safety, iii) Service reliability and iv) Agility (Borges Vieira et al., 2011). Table 3.3 presents the parameters assimilated from our review thereby will project a generic set of parameters that could be used for evaluations and decision making.

Table 3.3 Performance, enablers and barriers

Reference	Performance parameters	Enablers	Barriers
Echelmeyer et al., 2008a	-	• Optimal use of technologies • Competition • Scarcer resources • Ergonomic environments • Pressure for efficient processes	Different sizes and composition of packages.
Stoyanov et al., 2016	• Cycle time • Percentage unloaded successfully. • Amount of goods damage	• Lack of willingness • Ageing population • Strict labour-laws	• Parcel variety w.r.t different size, shape, weight, texture and material. • Identify, grasp and place securely. • Maintain human-like success rates and unloading times. • Chaotic and cluttered arrangement of goods.
Stavrou et al., 2018	• Minimum makespan • Maximum throughput • Minimum travel • Workload distribution	-	-
Gou et al., 2022	-	• Increased transhipment frequency • Truck LUL times.	• Uncertain positions, and dense stacks. • Traditional devices without intelligent detection systems.
Cosma et al., 2004	-	-	• Heavy installation requirements and rigidity of fixed navigation pathways. • Limited flexibility. • Position and pose of loads necessitate high precision handling. • Inability to use in special environments. • Lack of intelligence.
Chaikovskaia et al., 2021	• Cycle time • Loading time • Unloading time • System immobilisation time • Amount of payload • Planning horizon • Total distance	-	-
Bodenhagen et al., 2019	-	-	• Low dexterity robotic grippers. • Object manipulation in constrained conditions. • Understanding container content limited to plan manipulation actions for arbitrary objects. • Multiple aspects like processing of sensor information, falling boxes require understanding.
de Koster, 2018		• Space and Labour cost savings • Limited resource availability	• Requires considerable scale and high investments. • Hard to automate and may require regular manual interventions.

		• Reduced operational costs.	
Sindi and Woodman, 2021	-	• Reduced costs • Reduced lead time and cutting fuel costs. • Driverless trucks eliminate driver shortages and driver turnover. • Sizeable impact on overall business models. • Improved scheduling and lead time. • Reduced accidents • Few issues with worker's compensation, payroll tax, and healthcare benefits	• Employment loss • Implementing legislation particularly around insurance, ownership • Issue on level of information visibility on routes, capacity and lead time shared between logistics providers.
Garabini et al., 2020	• Operation time • Productivity performance • Reliability	• High market size of B2B and e-commerce with product variety. • Increased flexibility requirements.	• Handle product variability with different grasps. • Object configurations for inaccessible /flexible surfaces. • Strategies to effectively manipulate cuboids and cylinders
Molfino et al., 2015	Cost	-	-
de Jesús Ochoa-Olán et al., 2021	• Waiting time • Number of stops • Idle time • Total travel time • Operating speed	-	-
Kharitonov et al., 2021	-	-	• Reliability issues in solutions • High errors requiring frequent human intervention • Incorrect trajectory calculations • Mechanical constraints such as reduced degree of freedom, mechanical inability to grasp packages, or inaccurate package detection.
Echelmeyer et al., 2014	• Workspace (Rechable area) • Number of axels • Feasability	-	• Lack of process standardization • Undefined boundary and working conditions • Unknown quantity, position and orientation of goods • Require planar surfaces to hold objects. • Multiple packaging types (i.e. Palleted, Standardised and loose packaging)
Xu et al., 2021	-	-	• Multiple parcel specifications • Existing LUL tools not compatible with small units/multiple goods
Muscolo et al., 2015	-	-	No stakeholder ready to take initiative for adoption/investments.
Silvestri et al., 2019	-	Increasing customer demand and quality of life	-
Doliotis et al., 2016	• Pick attempts • Succesful picks • Success rate	• Increased production and distribution. • Labor intensive	-

	• Failures	• Expensive handling • Time consuming • Advancements in robotic perception and manipulation	
Scholz-Reiter et al., 2008	-	• Fulfil requirements within process times and costs. • Competitiveness requires high efficiency, flexibility, ergonomic aspects and minimisation of labour and overhead costs. • Potential of rationalisation and systemisation of processes and humanisation activities. • Developments in object recognition with laser-based systems and high-speed computer-based interpretation. • Development of special gripping system considering flexible and, autarky.	• Inability to independently detect objects. • Requirement to know predefined conditions of goods. • Slow operation times • Undefined parcel conditions require flexible and robust object recognition systems. • Require free space above parcels to grip, thereby wasting valuable loading space.
Cao and Dou, 2021	-	Rapid automation of logistics and warehouse operations	• Inability to guarantee positioning accuracy • Slow operation speed • High costs • Not suitable for both indoor and outdoor operations
Gustafsson-Skoglund and Södereng, 2012	• Productivity measurement • Cost effectiveness • Ergonomics • Feasibility • Safety • Applicability	• High absenteeism of employees. • Seasonal peaks in demand, • Accuracy and repeatability	• Varying demands justifying investments • Broad variety of carton sizes, weights and orientations require varying number of gripping devices • High costs and low ROI.
Vaskevicius et al., 2017	• Time for operation. • Number of operators saved	• Manual labour under dirty, dull, dangerous conditions • Labour laws • Time • Cost	Handling of shapes other than box-shaped objects.
Monica et al., 2020	• Boxes detected • Time to detect boxes	-	-
Bharadwaj, 2020	Vehicle turnaround time	• Common facilities decrease unit costs and increase revenue earning. • Reduced losses in transport output, improved productivity and earning potential.	Confined nature of systems to handle limited types of goods, and when this requirement changes the cost increases.
Cooper et al., 2014	-	Meet up demands of higher delivery frequency	Reduced trailer utilisation

4. CONCLUSION AND FUTURE WORK

This research presents the results of a systematic literature review on ALUL technologies available. As an initiative, xx papers were reviewed to gain insights on research carried out on LUL technologies. LUL solutions claim benefit by being flexible and repeatedly perform heavy duty activities, optimisation of associated transport and efficiently handle increasing frequencies. However, it is found that recent research do not focus on the importance of advancements in LUL technologies as a vital secondary interface considering the initiation of autonomous transports. This research primarily purposes to review the importance of ALUL considering the increase implementation of autonomous transports without negating the benefits these technologies pose.

Though beneficial the review identified issues such as i) lack of standardised packaging, ii) need for integration between various informational and operational technologies and iii) rearrangement of resources inhibiting technology adoption. Apart from the internal factors inhibiting decision making, factors such as investments costs and infrastructure modifications also play decisive roles. With all these said, the adoption of appropriate technology proves necessary considering which technology to choose and what performance parameters need to be considered. This review attempts to answer and detail this questions.

Outcomes obtained from this research support practitioners and researchers by giving an overview of ALUL devices that could be used for these processes. The article further identifies the domains, performance parameters, enablers and barriers and technologies available assessed within the scientific community. This as a result enables interested personnel to gain an actual insight of where the technology stands within the research fraternity and also act as a starting point on exploring the end effects these technologies have on the overall supply chain. The research clearly reveals that even if studies highlight the supply chain issues to be a critical reason for developments, none of the research actually try to explore the actual end effects of these technologies.

The authors conclude that more research is still required that study the combined effects of technology type and system outcomes of these technologies that are constantly evolving. Future research should primarily emphasize a detailed framework suggesting the steps to be followed for adopting ALUL systems and their comprehensive effects on the supply chain. We positively suggest that the implementation of LUL technologies into an existing operation must be studied but also the aftereffects on the overall operations have to be noted. We think this to be the only possible way to interpolate the impacts these technologies poses justifying the huge investments these technologies carry. Further research can also focus on determining implementation costs of ALUL systems in comparison to the overall warehouse costs and evaluating how improving this aspect can improve warehouse productivity is necessary.

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