‘Unit load’ evolution: a literature review from 1950-2020

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ABSTRACT

Most industrial products move through the supply chain grouped together, or in other words are carried in ‘unit loads.’ Unit loads facilitate and increase the efficiency of material handling, storage, and the distribution process. Moreover, unit loads reduce handling costs and the probability of damage by reducing individual unit handling. With the novelty of Industry 4.0, logistics and material handling systems were forced to improve in order to cope with growth in new technologies. This paper presents a literature review of publications on unit load problems, as well as builds analysis and draws conclusions for the unit load research timeline through the past several decades (from 1950 to 2020). Approximately 115 different articles and resources were collected and investigated thoroughly to compare their objectives, contributions, methodologies, conclusions, and gaps. This paper summarizes the result of this literature review, suggesting different classifications and findings.

Keywords: Logistics; Material Handling; Unit load; Unit Load Warehouse

INTRODUCTION

Industry 4.0 drives developments and improvements in many industrial sectors and forces for ‘Smart Factories’ and ‘Smart Logistics,’ which means that the supply chain, intralogistics, and material handling principles must all follow this evolution(Maslarić et al. 2016). One of the principles of material handling, the ‘Unit Load’ UL deserves special attention. A UL is a package or set of items that are combined and collected in order to make efficient handling easier. All firms, factories, and warehouses transfer and handle their products in the ‘unit load’ form. However, the UL can take various forms (barrel, bale, crate, sack, box, pallet, skid, tote pans, container, etc.) depending on the different industries and fields. Despite the UL’s simple concept, multiple operations rely heavily upon it, such as the areas of transporting, storage, packaging, and distribution. Moreover, ever since the UL was first introduced in the military and industrial fields, and because of its massive impact, the UL has attracted researchers’ attention globally.

Over the years, ULs have been an essential module in the supply-chain industry that has revolutionized the biosphere of packaging, transferring, and transporting operations. One significant contribution is the need to shift the handling of ULs from human power to that of machines and equipment, which makes the material handling process more feasible, effective, and efficient (Saputro et al. 2015). Numerous tools and pieces of equipment were invented and manufactured in order to serve this purpose. Some of the developed machines were used to create the UL itself (stretch-wrap machines, palletizers, bundle machines, etc.), while others were used to transfer and handle ULs (conveyors, pallet jacks, platform trucks, Automated Guided Vehicles [AGV], monorails, cranes, etc.) (Tompkins et al. 2010).

Using machines and automation to deal with ULs has led to the need for standardizing ULs. Several standards and regulations have been created as an attempt to facilitate the automatic handling of ULs, as well as testing and validation processes. These standards have helped dramatically in terms of promoting the design and manufacturing of Material Handling Equipment MHE. For decades, various researchers, engineers, designers,

manufacturers, and distributors have all been working on the vast number of available and required ULs. Their goals have been to reduce the variety in ULs, optimize the cost and efforts needed in material handling, and create or choose the best UL, in addition to designing or selecting the best MHE, storage places, and storage conditions.

Furthermore, the aim has been to choose the optimal data collection method, data management, and communication equipment. Each of these mentioned areas have become a solid base for many patents and research projects. This paper intends to study and analyze the evolution of the UL concept by examining published works from 1950 until 2020 to learn more about how researchers have investigated the UL for the past 70 years.

REVIEW METHODOLOGY

The systematic literature review of this work has been conducted to answer the questions related to the UL topic and in what context it was carried out in the research. The main guiding question for this research is the way in which the UL has been addressed. In addition, some other research questions were investigated, such as: how researchers refer to the UL, what methodologies have been used to analyze the UL problem, what type of inventions in MHE were related to UL, and what limitations have been faced during the UL research.

A common methodologies for literature review in supply chain were followed to answer these questions, starting with material collection step followed by descriptive analysis, then category selection process, and finally material evaluation (Seuring et al. 2012).

In the material collection phase, the scope of the research includes all the journal and conference papers that contain one phrase of the followings in their title or keywords: unit load, load handling, material handling, pallet load. Books and project reports were excluded. The present review tried to find all work registered and published regardless of the time period to record the chronological progress in the field of UL.

In the descriptive analysis phase, the collected published work was analyzed, then the primary results were subdivided according to the year and country of publication, in addition to the research objective, methodology and limitations.

In the category selection phase, the following categories were used to analyze the finding:

- General information: which includes publication year, the title, and the country of work.
- Main objective: This category includes the main topic of the article, which can be one of the followings: UL design, MHE design or selection, Inventory systems and Load utilization
- Solution methods: which focus on the method used in solving the UL problem, such as exact methods, heuristic procedures, simulation, policies, and support tools.
- Performance measures: this category highlighted the primary measures used for optimizing the UL problem or enhancing the operation; dimensions, time, cost, operational efficiency, human factor, and standards.
- Considerations and limitations: describe what limited the analyzed model including warehouse capacity and UL design, logistics resources and operation configuration.

In the material evaluation phase, the relevant articles were reviewed and analyzed according to the points mentioned in ‘category selection’ section. The results and findings were discussed to come up with the seen trend for the future work and finally to draw the conclusion for this work.

FINDINGS

The methodology described in the previous section was applied and resulted in having 178 initial articles, then a detailed analysis and evaluation for the documents was conducted focused on the relevance and quality of the work and results in reducing the number of related articles to be 115. As shown in Figure 1, it was realized that the UL publications started by the year 1950, however starting from the year 1998 the research activities in the field of UL have increased dramatically and this could be due to the growing interest in managing more efficient supply chain networks.

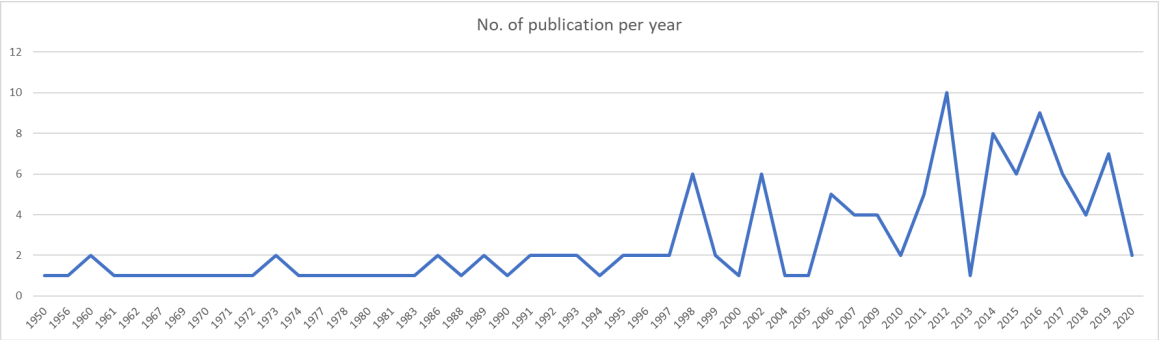

Figure 1 Number of Unit Load Publications per year (1950-2020)

Publications discussing the UL originated from a variety of different countries; approximately 28 countries were recorded. Notably, 46% of the papers originated from the United States. Researchers from various other countries also contributed to the topic, such as Canada, South Korea, India, China, Italy, Sweden, and Taiwan.

Several solution methodologies were used by authors to solve the UL problem, many of which used more than one methodology at-a-time to enhance the findings or to compare and validate results. Only 32 % of the reviewed publications were case studies (37 publications), 21% were patents (24 publications) and the rest 47% used one or more models (45 publications).

Based on the existing research, the relevant available documents in the early years were mostly unit loads handling apparatus designs and patents. In Table 1, the reviewed patents and their contribution are categorized into three categories, most of the contributions are inventions related to MHE improvements, two patents are related to forming the UL itself, and three patents were related to UL handling systems.

Table 1. Patents articles and their contribution sector.

Contribution	Author
Design a MHE or part of it or improve on available solutions	(Vogel et al. 1950; Cheshire 1960; Ulinsk 1961; Joseph P. Akrep 1962; Addison et al. 1967; Barry 1970; Bohlin et al. 1971; Bennett et al. 1973; Carl W. Oehler 1974; Ambrose 1977; Kaufman 1980; Donnelly 1981; Martin M. Wildmoser 1986; Dacus 2010; Franz Hornhofer 2006; Veitch 2004; Arlt et al. 2002; Pater 1999)
Design new UL design	(Ehlers 1956)
Design UL handling system	(Bryan et al. 1960; Zheng et al. 2014; Barry 1972)

The case studies were applied in different sectors including airlines, automotive, construction, food, hardware, industrial manufacturing, logistics, retail distributors, thermal power plant and wood pallet repair facilities. Table 2 shows publications focused on each industrial sector.

Table 2. The case studies industrial sectors.

Case study sector	Authors
Airline	(Baxter et al. 2014; Baxter et al. 2015; Mommens et al. 2016; Liu et al. 2019; Sahun 2019; Emde et al. 2020; Lu et al. 2012; Lu et al. 2011; Widyanesti et al. 2016)
Automotive	(Hanson et al. 2014)
Construction	(Yan et al. 2015)
Food	(Twede et al. 2007; Gagliardi et al. 2012; Company 2014; Wasala et al. 2015; Choi et al. 2020; Strobel et al. 1969; Bortolini, Botti, et al. 2015; Manzini et al. 2016)
Hardware	(Hwang et al. 1996)
Industrial Manufacturing	(Molina et al. 2018; Oser 2007)
Logistics	(Robert J. Bush et al. 1998; Jin et al. 2007; Carlo et al. 2012; Roy et al. 2015; Ang et al. 2019; Hompel et al. 2006)
Retail distributors	(Singh et al. 2014; Trevino et al. 1989; Morabito et al. 2000; Baker et al. 2016; Singh et al. 2017; Göransson et al. 2018)
Thermal power plant	(Guo 2006)
Wood pallet repair facilities	(Park et al. 2017)

Table 3 shows the 54 articles that used different models with full analysis on the main objective of each article, the used solution method, the calculated performance measures and the limitations and considerations. As noted from Table 3, the reviewed articles discussed more than one main topic in most cases, the UL design topic was discussed 17 times, were the MHE design and selection, inventory systems and load utilization were discussed 8, 30 and 13 times, respectively. The high focus on the inventory system shows that the UL topic gains its importance from the great integration with supply chain and logistics applications.

The Exact methodology was used 26 times in which different methods were recorded, such as non-linear programming, mathematical models of mixed-integer programming, Dynamic programming, generalized linear regression model, robust optimization, and analytical models. Sixteen authors used different heuristic approaches and algorithms, like hierarchical and sequencing procedures. Polices were also recorded, specially for the class-based and random-based methods in addition to rearrange-while-working RWW method. Fifteen authors used simulation and computer-aided design CAD in their work.

Time, cost and the UL optimum size are of the major performance measures that were highlighted in the reviewed articles in addition to the operational efficiency, which includes the consideration of UL mechanical strength, material used, versatility and the ease of unitizing and stacking.

Many limitations and considerations were recorded in the reviewed articles and can be classified into four main categories: warehouse capacity, UL design, logistic resources, and operational configurations. Around half of the articles mentioned the operational configuration as a limitation in their work; this may include UL materials and characteristics, quantities to be handled and its duration, information management systems, and the time consumed in preparing the UL itself. Other authors focused on the capacity and space for the storage and distribution areas or the logistics of the facility and the available MHE and manpower. In some papers the UL design was the limitation due to the small size of the UL or its very lightweight.

Table 3. Classification of the model articles.

Author	Main objective				Solution methods						Performance measures						Considerations/limitations			
	ULD	MHED	IS	LU	ET	HEU	EXP	SIM	POL	ST	DM	TM	CST	OE	HF	STD	CP	ULD	RC	ORE
(Scott et al. 1983)		x			x	x							x	x						
(Emamizadeh et al. 1986)			x		x	x							x							x
(Egbelu et al. 1988)			x		x						x	x								
(Schall et al. 1989)	x		x	x	x						x		x			x	x			x
(Goetschalckx et al. 1990)			x			x		x			x	x								x
(Houshyar 1991)				x		x					x	x	x				x	x	x	
(Egbelu 1991)	x	x			x						x	x						x		
(Mahadevan et al. 1992)	x				x	x					x	x		x				x		
(Egbelu 1993b)		x	x		x			x					x						x	x
(Egbelu 1993a)	x	x				x		x			x	x	x				x	x		
(Bengtsson et al. 1995)	x			x				x						x				x		
(Randhawa et al. 1995)		x	x					x			x	x					x			
(Lee et al. 1996)			x				x					x		x						x
(Van Den Berg et al. 1998)			x			x						x			x		x		x	
(Noble et al. 1998)	x	x		x		x					x	x	x						x	
(Beamon et al. 1998)	x				x						x	x						x		
(Beamon et al. 1998)	x				x						x	x	x	x				x		
(Malmborg et al. 1998)			x		x				x							x				x
(Moon et al. 1999)	x				x	x							x	x				x		
(Janjic et al. 2002)	x								x					x						x
(Breton et al. 2002)					x						x							x		x
(Castillo et al. 2002)			x		x						x	x								x
(Hwang et al. 2002)	x	x			x	x								x					x	x
(Yin et al. 2006)			x					x				x								x
(Kuo et al. 2007)				x	x							x		x					x	

Author	Main objective				Solution methods						Performance measures						Considerations/limitations			
	ULD	MHED	IS	LU	ET	HEU	EXP	SIM	POL	ST	DM	TM	CST	OE	HF	STD	CP	ULD	RC	ORE
(Meller et al. 2009)			x		x						x		x				x			
(Meller et al. 2009)			x			x						x	x	x					x	
(Sari 2009)			x		x						x	x	x							x
(Zúñiga et al. 2011)				x		x					x					x		x		
(Chen et al. 2011)			x							x	x	x								x
(Pohl et al. 2011)			x		x									x						x
(Ceylan et al. 2012)			x				x	x			x		x		x	x			x	x
(Ang et al. 2012)										x		x		x						x
(Öztürkoğlu et al. 2012)			x					x				x		x						x
(Lerher et al. 2012)			x					x			x	x								x
(Illés et al. 2013)	x			x	x						x					x		x		x
(Meneghetti et al. 2014)			x					x	x					x		x				x
(Goetschalckx et al. 2014)			x					x				x								x
(Popiela et al. 2014)	x				x						x								x	
(Bortolini, Botti, et al. 2015)			x		x						x	x	x							x
(Bortolini et al. 2016)			x		x							x							x	x
(Guo et al. 2016)			x		x						x	x	x				x		x	
(Lewandowski 2016)	x			x					x							x				
(Mladenović et al. 2016)			x		x								x	x					x	
(Kim et al. 2016)			x	x		x					x	x								x
(Rao et al. 2017)			x					x		x				x						x
(Mercier et al. 2017)	x					x								x		x		x	x	
(Gangadhar et al. 2017)	x						x							x		x				x
(Park et al. 2018)	x						x	x						x				x		
(Cardona et al. 2018)			x	x	x						x							x		
(Rijal et al. 2019)				x		x		x						x				x	x	
(Tang et al. 2019)			x	x		x						x		x				x	x	x

Author	Main objective				Solution methods						Performance measures						Considerations/limitations			
	ULD	MHED	IS	LU	ET	HEU	EXP	SIM	POL	ST	DM	TM	CST	OE	HF	STD	CP	ULD	RC	ORE
(Safronov et al. 2019)			x	x	x							x								x
(Martins et al. 2019)		x					x	x						x						x
Total number of articles 54	**17**	**8**	**30**	**13**	**26**	**16**	**5**	**15**	**4**	**3**	**25**	**28**	**16**	**22**	**2**	**9**	**7**	**16**	**15**	**29**

ULD	UL design	**DM**	Dimensions
MHED	MHE design or selection	**TM**	Time
IS	Inventory systems	**CST**	Costs
LU	Load utilization	**OE**	Operational efficiency
ET	Exact methods	**HF**	Human factors
HEU	Heuristics procedures	**STD**	Standards
EXP	Experimental	**CP**	Warehouse or facility capacity
SIM	Simulation	**ULD**	unit load design
POL	Policies	**RC**	Logistics resources
ST	Other supporting tools	**ORE**	Operational configuration

TRENDS AND FUTURE RESEARCH

The UL problem becomes more complex when the number and size of stock-keeping units SKU is massive or when SKUs are not following specific standards, in addition to four main categories of limitations and consideration in the UL problem as illustrated in Table 4.

Table 4. Categories of recorded limitations and considerations in the UL problem.

Warehouse capacity	unit load design	Logistics resources	Operational configuration
UL and space utilization.	Weight limitations.	Loading and unloading techniques.	Material and its characteristics.
Environmental aspects	Volume limitations.	Handling equipment and other handling aids.	Quantity to be handled and duration.
Limitations of aisles, doors, height, column, machine arrangement, and storage space dimensions, etc.	Cost of consumable (expendable) unitizing materials.	Worker welfare	Information management
		Cost of the entire handling system.	Time consumed in preparing the UL

From the analysis of this work, we will focus on two aspects for future work that were not covered with enough publications from the researcher's point-of-view; these aspects are environment and information management.

Environmental aspects are one of the most essential points to be studied in UL problem for sufficient use of green material and factories, in addition to energy efficiency. We suggest that more work should be done to cover these aspects (Bortolini, Faccio, et al. 2015).

Within the framework of information management, it was highly noticeable that the number of articles covered this aspect in the UL problem is deficient and limited. Information management system, data mining and proper use of technology in dealing with the dynamic UL problem needs more work (Mladenović et al. 2016).

One additional point in the future work aspect is related to the paper published in a language other than English. It is recommended to extend this paperwork to cover articles related to the UL problem but published in other languages.

CONCLUSION

This paper aimed to report on the importance of the unit load principle as one of the essential principles in material handling systems by highlighting the manner of discussing this principle throughout history. This was achieved by conducting a literature review from 1950 up to the current year (2020) covering approximately 115 different articles. The reviewed publications was classified first into three sections: patents, case studies and model.

Patents were classified depending on the invention role in the UL problem, while case studies application sectors were summarized. For the model articles, detailed analysis was presented to cover the main topic covered, method used, indicators measured, and limitations recoded in each work. Two main future work areas were highlighted in this work so that some areas related to UL problem will be better analyzed.

During the current period, the unit load is known to play a significant role in efficiently impacting the time and cost assigned to material handling, which explains why around 50% of papers and publications have been published in the last ten years. Thus, this concept is expected to grow and develop further after more research studies are conducted in the near future.

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