Autonomization and Digitalization: Index of Last Mile 4.0 Inclusive Transition

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Abstract. While autonomization and digitalization solutions appear beneficial within last mile delivery process, the literature on these solutions remain fragmented and distributed across different themes among various research papers. This paper aims to assemble some of the prominent solutions and outline their key characteristics to guide our researchers in future studies. To do so, this paper first extensively investigates the available literature and presents the most prominent solutions in a prioritization and categorization method (PCM) approach. Where these solutions currently stand in the perspective of inclusive last mile 4.0 transition is then discussed in our findings.

Keywords: Autonomization · Digitalization · Last mile delivery · Last mile 4.0 · Big data · Logistics 4.0

1 Introduction

Innovative solutions based on autonomization and digitalization (A&D) appear promising in logistics, given that their employment can contribute to cost-reduction, operational competitiveness, and environmental sustainability (Winkelhaus and Groose 2020, Hahn 2019, Seghezzi et al. 2020, Xu et al. 2020). While several stages of supply chain are becoming more automated each day, the last piece of this chain, the last mile delivery, faces complex struggles to completely automate its processes. *Increase in demand*—online purchases have been increasing with a rapid pace (Kiba-Janiak et al. 2021, Mucowska 2021, Tsai and Tiwasing 2021, Simoni et al. 2019, Zhou et al. 2020, Aurambout et al. 2019), triggered largely by the current Covid19 pandemic (Wang et al. 2021). While higher demands lead to higher congestions, Winkelhaus and Groose (2020) build the logistics 4.0 framework that integrates the modern technological solutions that help in building future strategies and accomplish the tasks. *Customer expectations*—companies are called to address increasing consumers' expectations related to a delivery's timeliness, costs, or environment impact (Comi and Savchenko 2021, Kiba-Janiak et al. 2021, Rossolov et al. 2021, Tsai and Tiwasing 2021, Saetta and Caldarelli 2020, Viu-Roig and Alvarez-Palau 2020). *Driver Shortages*—Last mile delivery is explained to be 'physically demanding' with 'strict time constraints'. Over the last years, there is an increasing gap in the shortage of drivers and warehouse handlers available, which

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motivates to look for alternative solutions. A&D has proven to provide high efficiency, while keeping up with the accelerating growth, in other verticals of supply chain, fostering the inclusive transition of last mile delivery within logistic 4.0. However, manifold implications are associated to the implementation of A&D in last mile, from regulatory specificities (Hoffmann and Prause 2018, Elsayed and Mohamed 2020), to customers' acceptance (Mangiaracina et al. 2019, Tsai and Tiwasing 2021), to job losses paradigm, social impact (Feng et al. 2017) and beyond. Due the aforementioned, not many studies have taken the lenses of the new solutions to the inclusive transition of the last mile into Logistic 4.0. This paper takes the challenge to index A&D references based on different areas of importance. Our findings argue the currently stands of A&D in the perspective of inclusive last mile 4.0 transition. In the results, we indicate the viability and the time frame of optimization possibilities.

2 Literature Review

By performing an interdisciplinary assessment of existing literature, this research was able to assemble several viable last-mile innovative solutions recently identified by researchers, namely unmanned aerial vehicles, autonomously driving robots, underground delivery, parcel lockers, reception boxes, customer's car trunks. It was also identified that big data, dynamic pricing and crowdsourcing logistics (Kiba-Janiak et al. 2021, Ranieri et al. 2018). Main solutions are discussed in the sequence.

Unmanned Aerial Vehicles (UAVs): commonly referred as 'drones', can be employed to deliver a parcel to a final destination (Bosona 2020, Di Puglia Pugliese et al. 2020, Elsayed and Mohamed 2020, Seghezzi et al. 2020, Aurambout et al. 2019, Maghazei and Netland 2019, Zhu 2019, Ranieri et al. 2018). Drones can navigate to such a destination and deposit a parcel by means of an embedded GPS (Mangiaracina et al. 2019), and subsequently return to their point of departure following the delivery. Researchers have assessed both stable optimal locations of such departures and returns (Aurambout et al. 2019), as well as the feasibility of moving locations via the use of trucks (Di Puglia Pugliese et al. 2020, Mangiaracina et al. 2019). There is contribution towards environmental sustainability and their potential to reduce the GHG emissions (Elsayed and Mohamed 2020, Mangiaracina et al. 2019).

Autonomously Driving Robots: can be defined as "[…] self-driving road vehicles that, moving on determined and controlled paths […]" (Mangiaracina et al. 2019, p. 14). Researchers have distinguished between semi-autonomous and fully autonomous vehicles (Ranieri et al. 2018) and have assessed possibilities for the optimization of existing ground robot prototypes such as FURBOT (Silvestri et al. 2019). Benefits relates of minimizing last-mile delivery costs while existing regulatory could be associated challenges to their application (Seghezzi et al. 2020; Hoffmann and Prause 2018).

Big Data: appears as a well-established information technology solution in last mile delivery within the literature explored with "ability to transform entire business processes." (Feng et al. 2017, p. 2) and to increase performance efficiency (Kiba-Janiak et al. 2021, Bosona 2020, Fosso Wamba 2020, Sarma et al. 2020, Dubey et al. 2019, Hahn 2019, Feng et al. 2017). Their application forms a significant aspect of Logistics 4.0, as it is directly associated to digital technologies that enable the formation of (semi) autonomous networks.

Parcel Lockers or Cabinets: refer to "[…] a form of self-service technology used for customer pick-up and return of e-purchased goods." (Vakulenko et al. 2019, p. 3). Specifically, "[…] a locker can be opened with a unique pickup code sent by e-mail or short message service on one's own phone." (Ranieri et al. 2018, p. 8). Researchers have established the existence of facilitating conditions related to the usage of parcel lockers as a factor increasing this solution's acceptance (Tsai and Tiwasing 2021, Zhou et al. 2020). The benefit of this solution in minimizing last-mile delivery costs is straightforward (Kiba-Janiak et al. 2021, Bosona 2020, Mangiaracina et al. 2019, Zhu 2019, Florio et al. 2018), as it eradicates face-to-face human interaction of customers and couriers and thus can be distinguished from the similar solution of pick-up points (Mucowska 2021, Mangiaracina et al. 2019).

There are several other solutions identified during our literature search. One such solution pertains to the use of destination locations owned by customers. Such locations can be either fixed, namely 'reception boxes' situated in a customer's residence (Hoffmann and Prause 2018), or shifting, by means of delivery in a 'customer's car trunk'. While the value of those solutions in minimizing last-mile delivery costs is similar to parcel lockers and straightforward (Mangiaracina et al. 2019, Florio et al. 2018).

Another solution is that of 'Dynamic pricing', namely "[…] associating different delivery prices to different time windows." (Mangiaracina et al. 2019, p.14). This aims to optimize the last-mile delivery process by considering customers' preferences. The benefits of this solution in minimizing last-mile delivery costs of e-grocery delivery have been established (Mangiaracina et al. 2019). Whereas 'Crowdsourcing logistics' is a term referring to the possibility of engaging people directly in the last mile delivery process per se, by "outsourcing the delivery of the goods to 'common' people that give their availability for bringing the parcel from a point of collection, generally a warehouse or a store, to a point of delivery" (Lazarević and Dobrodolac 2020, p. 2). While the benefits of this solution in minimizing last-mile delivery costs have been established (Ghaderi et al. 2022, Kiba-Janiak et al. 2021, Bosona 2020, Lazarević and Dobrodolac 2020, Mangiaracina et al. 2019, Zhu 2019), further research is needed in order to better assess the value of different crowdsourcing logistics business models (Mangiaracina et al. 2019, p. 16), given that the application of this solution may incur negative externalities (Simoni et al. 2019, Zhu 2019).

3 Methodology

To index all automation and digitalization solutions technologies which are viable solutions to address last-mile delivery inefficiencies, we have compiled available literature in Sect. 2 according to various A&D solutions. We have identified four verticals upon which the characteristics of each autonomous solution are highlighted. While 'benefits' and 'challenges' remain the most studied characteristics among the papers reviewed, 'efficiency' and 'implementation time frame' make up the four verticals.

Taking the premise of the inclusive transition of the last mile into Logistic 4.0, the prioritization and categorization method (PCM) is then applied as following: High, Moderate, and Low. E.g. 'High' cost benefit is where the potential to realize cost benefits through using a particular solution shows great prospect. Furthermore, where enough information is not available to make an educated inference, 'N/I' is highlighted. The results provide where these innovations currently stand.

4 Results and Discussion

Where do These Innovations Currently Stand? The use of both UAVs and Autonomous robots as optimization solutions has been frequently examined. Researchers have created analytical models based on the employment of drones or robots, with the aim of minimizing last mile delivery costs (Di Puglia Pugliese et al. 2020, Aurambout et al. 2019, Silvestri et al. 2019) or introducing a sustainable delivery solution (Elsayed and Mohamed 2020). Table 1 gives an overview of the characteristics of A&D solutions being studied.

Table 1. Characteristics of inclusive Last Mile 4.0 transition

	Benefits		Challenges		Time frame	Efficiency
	Cost	Environmental	Legal	Technological	Optimization possibility	
UAV's	Moderate-Low	High	High	High	Long term	Moderate
Autonomous robots	Moderate	High	High	High	Mid term	High
Parcel lockers	High	High	Low	Moderate	In use	Moderate
Big data	High	High	Low	Moderate	In use	High
Reception boxes	Moderate	Low	Low	Low	Short term	Moderate
Dynamic pricing	High	Moderate	Low	Low	In Use	Low
Crowdsourcing	High	Moderate	N/I	Moderate	Short term	Moderate

Research involving collaboration with companies that have opted for the use of drones or robots (Hoffmann and Prause 2018) is fundamental to identify the practical challenges of their application. Customer acceptance as well as on their societal impact could identify unforeseen complexities of their use. Parcel lockers and the customers' behaviour are valuable insights regarding factors that impact on their initial intention to adopt new solutions (Tsai and Tiwasing 2021, Zhou et al. 2020), as factors that impact the continuation of its use (Vakulenko et al. 2019). Big data applications have been thoroughly studied by the academia. Within the literature examined, the Internet of Things has been identified as the principal application of Logistics 4.0 (Winkelhaus and Grosse 2020), and attention has been given to the increasing dependence of SCM on big data use, the importance of data manipulation capacity as well as on questions regarding data quality (Feng et al. 2017). Regarding the last-mile, researchers have established that their use has a positive impact towards cost minimization (Kiba-Janiak et al. 2021, Bosona 2020, Fosso Wamba 2020, Sarma et al. 2020, Dubey et al. 2019, Hahn 2019, Feng et al. 2017) based on the creation of analytical and simulation models (Sarma et al. 2020, Shan et al. 2019, Zhang et al. 2019). The use of Information and Communication Technologies (ICT) has been associated with collaborative urban logistics, the optimization of transport management and routing city logistics as well as innovative mobility infrastructure (Ranieri et al. 2018).

5 Conclusion

While A&D is poised to provide numerous benefits within the last mile delivery process, inclusive potential for last mile 4.0—literature on this subject remains to be fragmented and distributed across numerous research papers in different themes. This paper introduces several reasons why A&D is sought after to provide solutions to the challenges last mile process currently faces. Supply Chain Management is poised to be one of the biggest benefactors of A&D, however their implementation in last mile is still limited to theory. Even then so, there is a keen interest in the research community to understand the applications of these solutions in transition to a last mile 4.0. With the proposed index of current solutions and time frame of optimization possibilities, we thus argue the inclusive transition of the last mile within Logistic 4.0. Future research can delve deep into other inclusive last mile 4.0 characteristics.

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Appendices

Appendix 1. Measurement and Data Structure—'Benefits'

Benefit level	Benefit dimension	Item examples and references
High	Cost	**Parcel lockers** (Viu-Roig and Alvarez-Palau 2020, Mangiaracina et al. 2019, Vakulenko et al. 2019, Zhu 2019) **Big data** (Saetta and Caldarelli 2020, Sarma et al. 2020, Xu et al. 2020, Dubey et al. 2019, Hahn 2019, Winkelhaus and Grosse 2020, Zhang et al. 2019, Ranieri et al. 2018) **Dynamic pricing** Mangiaracina et al. (2019) **Crowdsourcing** Comi and Savchenko (2021), Kiba-Janiak et al. (2021), Seghezzi et al. (2020), Viu-Roig and Alvarez-Palau (2020), Mangiaracina et al. (2019), Florio et al. (2018)
	Environment	**UAV's** (Elsayed and Mohamed 2020, Lazarević and Dobrodolac 2020, Mangiaracina et al. 2019, Zhu 2019) **Autonomous robots** (Lazarević and Dobrodolac 2020, Mangiaracina et al. 2019, Ranieri et al. 2018) **Parcel lockers** (Mucowska 2021, Viu-Roig and Alvarez-Palau 2020) **Big data** (Mucowska 2021, Bosona 2020, Fosso Wamba 2020, Saetta and Caldarelli 2020, Shan et al. 2019, Winkelhaus and Grosse 2020, Ranieri et al. 2018)
Moderate	Cost	**UAV's** (Bosona 2020, Di Puglia Pugliese et al. 2020, Lazarević and Dobrodolac 2020, Aurambout et al. 2019, Maghazei and Netland 2019, Mangiaracina et al. 2019, Zhu 2019) **Autonomous robots** (Lazarević and Dobrodolac 2020, Mangiaracina et al. 2019, Hoffmann and Prause 2018, Ranieri et al. 2018) **Reception boxes** (Viu-Roig and Alvarez-Palau 2020, Mangiaracina et al. 2019)
	Environment	**Dynamic pricing** Mangiaracina et al. (2019) **Crowdsourcing** Ghaderi et al. (2022), Comi and Savchenko (2021), Kiba-Janiak et al. (2021), Mucowska (2021), Simoni et al. (2019), Viu-Roig and Alvarez-Palau (2020)
Low	Environment	**Reception boxes** Viu-Roig and Alvarez-Palau (2020), Mangiaracina et al. (2019)

Appendix 2. Measurement and Data Structure—'Challenges'

Challenges level	Challenges dimension	Item examples and references
High	Legal	**UAV's** (Bosona 2020, Elsayed and Mohamed 2020, Lazarević and Dobrodolac 2020, Viu-Roig and Alvarez-Palau 2020) **Autonomous robots** (Viu-Roig and Alvarez-Palau 2020, Hoffmann and Prause 2018, Ranieri et al. 2018)

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Challenges level	Challenges dimension	Item examples and references
	Technology	**UAV's** (Bosona 2020) **Autonomous robots** (Lazarević and Dobrodolac 2020, Ranieri et al. 2018)
Moderate	Technology	**Parcel lockers** (Tsai and Tiwasing 2021, Vakulenko et al. 2019) **Big data** (Bosona 2020, Shan et al. 2019, Winkelhaus and Grosse 2020) **Crowdsourcing** (Ghaderi et al. 2022, Seghezzi et al. 2020)
Low	Legal	**Parcel lockers** (Tsai and Tiwasing 2021) **Big data** (Shan et al. 2019) **Reception boxes** (Mangiaracina et al. 2019) **Dynamic pricing** (Mangiaracina et al. 2019)
	Technology	**Reception boxes** (Mangiaracina et al. 2019) **Dynamic pricing** (Mangiaracina et al. 2019)

Appendix 3. Measurement and Data Structure—'Implementation Time Frame'

Implementation time frame	Item examples and references
Long-term	**UAV's** (Lazarević and Dobrodolac 2020, Bosona 2020, Viu-Roig and Alvarez-Palau 2020)
Mid-term	**Autonomous robots** (Kiba-Janiak et al. 2021)
Short-term	**Reception boxes** (Mangiaracina et al. 2019, Florio et al. 2018) **Crowdsourcing** (Kiba-Janiak et al. 2021, Mangiaracina et al. 2019, Florio et al. 2018)
In use	**Parcel lockers** (Tsai and Tiwasing 2021, Zhou et al. 2020, Vakulenko et al. 2019, Ranieri et al. 2018) **Big Data** (Fosso Wamba 2020, Sarma et al. 2020, Dubey et al. 2019, Hahn 2019, Shan et al. 2019, Zhang et al. 2019) **Dynamic pricing** (Mangiaracina et al. 2019)

Appendix 4. Measurement and Data Structure—'Efficiency'

Efficiency: optimization possibility	Item examples and references
High	**Autonomous robots** (Lazarević and Dobrodolac 2020, Silvestri et al. 2019, Ranieri et al. 2018) **Big data** (Fosso Wamba 2020, Saetta and Caldarelli, 2020, Sarma et al. 2020, Dubey et al. 2019, Hahn 2019, Shan et al. 2019, Zhang et al. 2019)

(*continued*)

(*continued*)

Efficiency: optimization possibility	Item examples and references
Moderate	**UAV's** (Di Puglia Pugliese et al. 2020, Aurambout et al. 2019, Maghazei and Netland 2019) **Parcel lockers** (Zhou et al. 2020, Mangiaracina et al. 2019) **Reception boxes** (Florio et al. 2018) **Crowdsourcing** (Ghaderi et al. 2022, Seghezzi et al. 2020, Simoni et al. 2019, Mangiaracina et al. 2019, Florio et al. 2018)
Low	**Dynamic pricing** (Mangiaracina et al. 2019)

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