Evolution of Automated Guided Vehicles (AGVs) in the Logistics 4.0 landscape: a classification framework and empirical insights

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Abstract: The increasing demand for highly customised products and short delivery lead times is requiring production and logistics systems to become more flexible and reactive to customers' requests. In this landscape, the so-called fourth industrial revolution is fostering the development of new technologies which may help companies deal with the evolved customers' needs at reasonable costs. While this phenomenon has been widely addressed in the scientific literature with reference to manufacturing systems, only few and very recent contributions are dealing with the Logistics 4.0 paradigm, and specifically focusing on material handling systems. The purpose of this paper is to investigate the evolution of Automated Guided Vehicles (AGVs) in the Logistics 4.0 landscape. The research was structured into two main steps. First, a thorough review of the literature on AGVs led to the identification of their key characteristics. A classification framework for AGV solutions was developed, based on three dimensions: Navigation path, Communication, and Decision. In the second step, five European material handling technology providers were interviewed in order to validate the classification framework and gain insights on the AGV solutions available on the market. Results showed that AGVs are turning into highly flexible autonomous vehicles through the development of open navigation paths, Machine-to-Machine (M2M) communication and decentralised decision-making capabilities.

Keywords: Logistics 4.0; AGV; Autonomous vehicles; Classification framework; Empirical analysis

1. Introduction

In the current business landscape, technological evolution is opening up new opportunities for designing production and logistics systems, with the rise of Cyber Physical Systems (Napoleone et al., 2018). Companies can increasingly rely on the Internet of Things (IoT) to create digital representations of physical systems, called Digital Twins, characterised by real-time reflection, interaction and convergence, and self-evolution (Tao et al., 2018). Also new ways of sharing information are available, through human-machine interaction and machine-to-machine communication (Barreto et al., 2017). These elements are often summarised under the term "Industry 4.0" and represent the cornerstones of the ongoing fourth industrial revolution, which exploits process automation and data analytics to enable decentralisation of decisions (Hermann et al., 2016; Battaïa et al., 2018). So far, the academic literature on Industry 4.0 has mainly focused on production systems (Liao et al., 2017). Nevertheless, logistics represents a suitable application area for Industry 4.0 (Hofmann and Rüsch, 2017) and innovative transportation and material handling systems, integrated with sensors and digital tools, are increasingly available on the market. A few scholars have started to investigate the implications of Industry 4.0 paradigms applied to logistics, referring to the "Logistics 4.0" concept (Barreto et al., 2017; Strandhagen et al., 2017), but still little research exists about the evolution of material handling systems in this scenario. The purpose of this paper is to contribute to fill this gap by investigating the evolution of Automated Guided Vehicles (AGVs) in the Logistics 4.0 landscape. AGVs represent a fertile ground for Logistics 4.0 applications, which could transform them into connected objects that gather data through sensors and communicate with each other (Hermann et al., 2016). From an academic perspective, the paper offers an original classification framework for AGV solutions, based on three dimensions: Navigation path, Communication, and Decision. On the other side, given that relevance is also a question about whether a research is useful for practice (Stentoft and Rajkumar, 2018), available solutions on the market were positioned in the developed framework. From practitioners' perspective, Logistics 4.0 might allow for faster and decentralised decisions, helping companies deal with the evolved customers' needs at reasonable costs. The remainder of this paper is organised as follows. Section 2 describes the methodology adopted and Section 3 reports the results of literature review. Section 4 reports the main findings, including the classification framework and the insights from case studies. Section 5 includes discussion of the results and final conclusions.

2. Methodology

The research methodology consisted of two phases. A literature review was firstly carried out in order to deeply analyse the characteristics of AGVs, with a particular focus on the recent technological evolutions in this field. The literature search, performed on the search engines Scopus and Google Scholar, was based on a combination of keywords related to both Industry 4.0 technologies and Automated Guided Vehicles (e.g. "Industry 4.0", "AGV", "Cyber-Physical Systems", "M2M", "Logistics", "Mobile robot"). Because of the small number of relevant recent contributions in academic journals, also grey literature was included in the review process; this allowed to identify recent papers coping with the latest technological evolutions. After the literature search, a first selection of relevant papers was made based on titles and abstracts, in order to eliminate out-of-scope articles. A further screening was then carried out by reading the full text of the remaining articles, leading to the final selection of 13 scientific papers. The characteristics of AGVs described in these papers were analysed in detail and three main dimensions were identified to classify AGV configurations proposed in literature. According to these dimensions, commonalities among groups of vehicles were found, leading to the development of an original classification framework for AGVs based on three axes and three options for each axis. In the second phase, multiple case studies were conducted to investigate the phenomenon within its real business context (Rowley, 2002), i.e. to gain empirical insights about the current development of AGV solutions with respect to the acknowledged literature. European material handling technology providers were selected as unit of analysis. Sample selection was based on a theoretical sampling aimed at collecting information that best support the development of knowledge, driven by the presence of AGVs in the companies' product portfolio and by the availability of the companies (Yin, 2009). As suggested by Eisenhardt (1989), a suitable number of cases should be between four and ten. Hence, five European material handling providers were selected. Table 1 provides an overview about cases' features.

Table 1: Case studies

Case	Revenues (2017)	Product portfolio
A	Lower than 500 Million €	AGVs and automated picking solutions
B	Lower than 500 Million €	AGVs
C	Between 1 and 5 Billion €	Forklift trucks, tugger trains, AGVs
D	Higher than 5 Billion €	Integrated material handling and storage solutions
E	Higher than 5 Billion €	Industrial automation systems and robotics

For each case, interviews were carried out since they represent essential sources of case study information, allowing the reconstruction of events and providing perceived causal inferences (Yin, 2009). To guarantee technical competences about both AGVs design and management policies, both R&D managers and process engineers were interviewed. Interviews, characterised by an open-ended approach (Yin, 2009), lasted approximately 60 minutes and focused on the technical characteristics, management software, and managerial policies of the most recent AGVs developed by the companies, as well as on future developments of their technologies. Due to the sensitive nature of some technical characteristics, confidentiality was guaranteed to interviewees. Therefore, neither company nor interviewees' names will be revealed. Interviews were collected from April 2018 to November 2018. In order to increase the study's depth by corroborating evidences and insights emerged from the interviews, data triangulation was also an integral part of the process: the additional data sources were companies' websites, technical documents reporting vehicles specifications and success cases provided by the companies. Insights gained from case studies were used first of all to validate the three-axes classification framework, by testing if this framework effectively describes the differences among the AGVs developed by the case companies. Then, cases results were used to get an understanding of how AGV solutions available on the market are evolving in the 4.0 landscape.

3. Literature review

AGVs can be defined as self-driven vehicles used to transport unit loads inside a factory or a warehouse without the help of a human operator (Rocha et al., 2010). These vehicles have been used in factories and warehouses for more than fifty years: initially introduced to transport very large and heavy objects like rolls of uncut paper or engine blocks, AGVs are now deployed also to handle smaller unit loads (Kelly et al., 2007; Lourenço et al., 2016). Moreover, recent technological advancements in terms of inexpensive wireless communications, computational power, and robotic components are making autonomous vehicles cheaper and smaller, thus favouring their widespread adoption in different fields of application and industries (D'Andrea and Wurman, 2008).

AGVs are traditionally based on three main navigation technologies: wire guidance, inertial guidance, and laser guidance. AGVs based on wire guidance technology are able to sense inductively the wires embedded in the floor (Kelly et al., 2007) or the magnetic tape placed on the floor surface (Fedorko et al., 2017) in order to determine their relative position. More recent versions of this technology involve reflective, coloured tape on the floor surface without magnetic properties (Martinez-Barberá and Herrero-Pérez, 2010). In all versions, the paths described by the wire or tape corresponds to the only possible routes that the AGV may follow (Fedorko et al., 2017). Instead, AGVs based on inertial guidance rely on magnets placed on the floor at regular intervals to detect their position. Thanks to gyroscopes and wheel odometry, these vehicles are able to navigate blindly between two following markers (Kelly et al., 2007). Finally, laser-guided AGVs are equipped with a spinning laser emitter-receiver, detecting the vehicle's position through a triangulation of the distances from retro reflective landmarks placed in the building (Kelly et al., 2007; Reinke et al., 2013). In this case, a navigation software containing the map of the system is required (Martinez-Barberá and Herrero-Pérez, 2010). Besides traditional solutions, new types of flexible navigation technologies were proposed in literature. Kelly et al. (2007) introduced the concept of free-ranging systems, defined as systems able to deviate significantly from their guide paths. They proposed an AGV navigation technique based on computer vision, which allows to eliminate artificial landmarks: downward-looking vision cameras are placed on the vehicle and use floor mosaics as navigation maps to guide the vehicle through the shop floor. Free-ranging AGVs were studied also by Martınez-Barberá and Herrero-Pérez (2010): in the solution they introduced, vehicles still rely on laser navigation, but localisation is improved through odometry, i.e. through motion sensors that measure the change in position over time. Cardarelli et al. (2014) described a similar solution, in which the traditional laser guidance system is complemented with a set of sensors, both on the AGV and on the warehouse structure. In this case, sensors are also used to scan the environment, detecting possible obstacles and supporting an obstacle avoidance system. More recently, literature is discussing a new type of navigation technology, where vehicles are equipped with a set of sensors that scan the surrounding environment creating a virtual map of the warehouse (Fedorko et al., 2017). Natural landmarks, such as posts, poles, corners or walls are then extracted from this map and used for the self-localisation of AGVs without the support of any artificial landmarks: the only information needed for the localisation are the range, angle and distance between the vehicle and different natural landmarks and, in some versions, a digital map of the warehouse which is compared with the one scanned by the AGV sensors (Reinke et al., 2013).

Literature review also pointed out that AGVs are increasingly referred to as autonomous vehicles. Berman and Edan (2002) defined the autonomy of AGVs as their ability to manage mission allocation without a central node coordinating them; this is possible when each vehicle, equipped with wireless Ethernet communication devices, is able to communicate in real time not only with the central information system, but also with other vehicles and workstations. A more advanced solution was presented by Herrero-Pérez and Martinez-Barberá (2008), who described a Multi-Robot System (MRS) where AGVs communicate both with each other and with a central node. In this solution AGVs are managed through: a centralised policy for task allocation, aiming to reach a global optimum, and a decentralised policy for coordination problems in traffic control, which require to be solved in extremely short computing times. In particular, traffic control involves a direct negotiation among different vehicles that need to access the same area in a certain point in time: based on a local grid map of the environment and on a set of pre-defined rules, vehicles autonomously define priorities. A similar case was described by D’Andrea et al. (2008), who proposed vehicles that autonomously manage path planning decisions and are able to communicate with each other, with picking stations, and with a central Job Manager node in charge of task allocation. Also the hierarchical path planning algorithm proposed by Digani et al. (2015) combines a centralised approach with a decentralised one. In their solution, once sectors within the warehouse have been defined, a local coordination among AGVs is exploited to allocate resources to one vehicle at a time, in order to avoid deadlocks; a centralised node is involved only for global path planning, when a path crossing different sectors must be set. Literature provided also different solutions for the communication and management of AGVs. For instance, Farahvash and Boucher (2004) proposed a multi-agent system made by AGVs, manufacturing cells and four central software agents, where all decisions are taken by the software nodes. In particular, the Material Manager Agent assigns AGVs to requests for material movements that come from the manufacturing cell, and a Traffic Controller Agent is responsible for preventing collisions among vehicles. Kelly et al. (2007) presented a context in which AGVs have a local computation capability, used for localisation purposes; nevertheless, a direct machine-to-machine (M2M) communication is not allowed. Conversely, a central computer coordinates all the activities through a regular communication with all the vehicles. Lastly, Bottani et al. (2017) described a simple Job Shop made of four processing stations, in which the so-called Cyber-Guided Vehicles are able to communicate directly with stations and to autonomously decide which station to serve, based on an algorithm running on their microcontrollers.

4. Findings

4.1 Literature-based classification framework for AGVs

Literature review showed that several authors have investigated new AGV solutions over the last 15 years, mainly focusing on the evaluation of innovations in one or a limited number of key technical characteristics. However, a general framework describing all the possible solutions is still lacking; such a framework might be useful to clearly outline the main differences among AGVs, and to understand how these vehicles have been evolving. Therefore, the three-axes classification framework shown in Figure 1 was developed in this research. It consists of three dimensions, based on literature, which can be used to effectively describe all the AGV solutions previously discussed. For each dimension, three possible options were defined, in order to account for the main differences among AGVs.

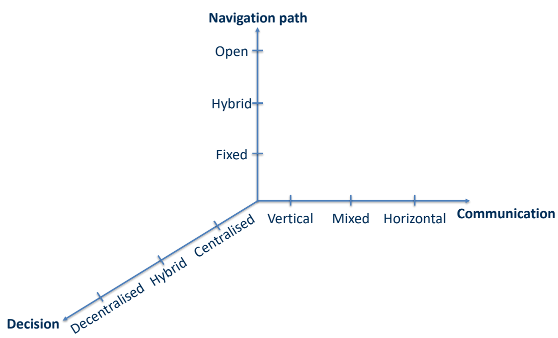

Figure 1: Literature based classification framework for AGVs

The first axis, *Navigation path*, is related to navigation technologies, which were clustered according to the flexibility of the AGV paths. In the first option, called *Fixed* path, the vehicles are constrained to follow a set of pre-determined routes and are not able to avoid any obstacles. This is the most rigid option: AGVs whose navigation technology is classified as *Fixed* can move only in areas where artificial landmarks, such as wires, markers or reflectors, have been conveniently placed. These solutions suffer from infrastructure dependence (Kelly et al., 2007): the installation of artificial landmarks is often time consuming and must be performed by skilled operators (Reinke et al., 2013; Oleari et al., 2015). Moreover, a damage to the infrastructures or a layout change may require the stop of the whole system for the modification of paths (Martinez-Barberá et al., 2009; Fedorko et al., 2017). This option was often presented in the reviewed literature as a base case, on which authors built their innovative solution. A more flexible option is the *Hybrid* one, in which navigation still relies on artificial landmarks, but vehicles are equipped with an obstacle avoidance system allowing them to deviate from their pre-determined path to go around obstacles. Herrero-Pérez and Martinez-Barberá (2008) introduced such solution, considering laser-guided AGVs able to detect obstacles through a multi-sensory system and to compute circular routes, alternative to the rectilinear ones set by the traditional laser navigation system. In the most flexible configuration, called *Open*, AGVs can navigate freely inside the warehouse or the shop floor, without the need for any artificial landmarks. Navigation relies on a virtual map of the area based on natural landmarks, created through sensors installed on the vehicle (Reinke et al., 2013). Thanks to this feature, vehicles can adapt to modifications in the environment: obstacles can be easily identified and avoided, exploiting data gathered through sensors, possibly complemented with further information registered through cameras on AGVs or sensing systems on the warehouse structure (Oleari et al., 2015). Even in case a layout change occurs, the only set up needed by AGVs is a scan of the new environment, repeated a few times (Fedorko et al., 2017).

The second axis, called *Communication*, refers to the data transmission capabilities of AGVs. In the *Vertical* option, AGVs are able to communicate only with a central node, which usually coincides with the Warehouse Management System or with another software agent acting as a communication and coordination manager (Oleari et al., 2015). All the vehicles send to this node information about their status (e.g. position and load) and get in return instructions and/or information about other vehicles' or workstations' status (Farahvash and Boucher, 2004). Alternative options on this axis rely on the so-called Machine-to-Machine (M2M) communication. More specifically, the *Horizontal* option refers to vehicles that directly communicate with each other and with other machines (Bottani et al., 2017), while the *Mixed* one accounts for AGVs with both direct M2M communication and communication to a central software node (D'Andrea and Wurman, 2008).

Finally, the third axis, *Decision*, copes with the management of AGVs and specifically with the decision maker node. Decisions might refer to path planning or mission assignment problems. In traditional configurations all decisions are *Centralised*, since only one or a few central nodes are in charge of processing data and giving instructions to AGVs. As Herrero-Pérez and Martinez-Barberá (2008) noted, centralised decisions lead to globally optimal solutions, since they can potentially consider information about the whole system; however, their complexity is usually high, and it increases with the number of vehicles to be coordinated, thus leading to long computational times that make it difficult to implement decisions in real time. Besides this traditional configuration, a new one is emerging, called *Mixed*: central nodes are still in charge of some choices, but AGVs have a local computation capability, allowing them to autonomously take some decisions. Finally, the last option is the *Decentralised* one, in which all decisions are delegated to AGVs. Looking at the type of decentralised decisions, path planning emerges as the choice that is more often delegated to AGVs, both in *Hybrid* and *Decentralised* configuration. However, most AGVs presented in the reviewed literature can autonomously solve just coordination problems in local traffic control, through a real-time direct negotiation with other vehicles (Herrero-Pérez and Martinez-Barberá, 2008; Digani et al., 2015); instead, the global path planning problem, considering the whole area where AGVs are deployed, is rarely decentralised (D'Andrea and Wurman, 2008). The second type of decision, i.e. mission assignment, is delegated to vehicles only in the fully *Decentralised* configuration: so far, this solution has been applied to simplified factory environments or small industrial subsystems, where one or a few AGVs autonomously decide which workstations to serve without the intervention of a central decision maker node (Berman and Edan, 2002; Bottani et al., 2017). However, the authors themselves imply that, when dealing with real industrial contexts, conflicts between resources may arise, making the intervention of a central coordinator still necessary (Bottani et al., 2017).

All the identified dimensions seem to be strongly related to the Industry 4.0 paradigm. Looking at the Navigation path axis, the *Open* option is characterized by the creation of a virtual map, which shares several characteristics with Digital Twins (Tao et al., 2018). In fact, the virtual map is a reliable representation of the physical system (Real-time reflection), created through sensors that acquire data in real-time and merge it with historical data (Interaction and convergence), and it is continuously updated through a comparison between physical and virtual space (Self-evolution). The second dimension, Communication, might involve connected objects that gather data through sensors and communicate with each other, according to IoT and M2M communication, indicated as one of the pillars of Industry 4.0 architectures (Hermann et al., 2016; Bottani et al., 2017). Finally, the opportunity to take decentralised decisions is one of the design principles of Industry 4.0 (Hermann et al., 2016): AGVs with such capability have all the characteristics of autonomous systems, that know their state and are able to execute high-level tasks without detailed programming or human control (Rosen et al., 2015).

The classification of the reviewed papers within the framework is reported in Appendix A, referring to the main solution proposed by each paper.

4.2 Case studies

After developing the classification framework, interviews were conducted with five European material handling technology providers, in order to validate the framework and gain insights on the AGV solutions available on the market. Interviews aimed to understand the technical characteristics, managerial policies and application domains of the latest AGVs developed by these companies, as well as on future developments of their technologies. As shown in Table 2, it was possible to set within the framework all the AGV solutions developed by the interviewed companies.

Table 2: Case studies classification within the framework

Case	Navigation path	Communication	Decision
A	Fixed	Horizontal	Decentralised
B	Open	Vertical	Centralised
C	Open	Mixed	Centralised
D	Fixed	Mixed	Hybrid
E	Open	Vertical	Hybrid

Company A is a medium-sized firm producing automated handling and picking systems. Its AGV solution targets industrial customers that want to automate material feeding of workstations. It is designed for production systems where AGVs visit all workstations with fixed time intervals, following a pre-determined route. It adopts a navigation system based on magnetic markers, combined with laser sensors used as safety devices for obstacle detection. AGVs are also equipped with an on-board computer which is able to fully control the vehicle, without the need of an external control centre, and to communicate with other vehicles, exchanging information about their position, load and status. Moreover, although this AGV is capable of taking fully autonomous decisions, the company also provides an optional link to a control centre, in case the customer wants to use its own software for mission allocation.

Company B focused on the development of an advanced infrastructure-free navigation system, eliminating the need for artificial landmarks. As a result, its AGVs are extremely flexible and their installation requires very little effort: after being guided through the building by an operator, the vehicles are ready to be deployed. This is possible since AGVs are equipped with a laser system that scans the surrounding environment, supporting the creation of a map based on natural landmarks. As regards task allocation and path planning activities, these vehicles are controlled by a fleet management software that centrally supervises task prioritisation and selection of the AGV which best suits each job, based on position and availability.

Like Company B, also Company C sells AGVs with a flexible navigation system: thanks to a laser scanner dedicated to navigation, vehicles create a reference map during installation and are then able to self-locate by identifying natural landmarks (i.e. walls, racks, columns, machines) inside the building. Each AGV communicates with a central task manager, in charge of all decisions. It is also possible for the vehicles to directly communicate with other machines such as conveyors and workstations, getting information about loads to be collected. However, also in this case all the data is sent by AGVs to the central manager node, that processes them and gives instructions to AGVs.

Company D produces laser-guided AGVs that navigate the warehouse relying on adhesive reflectors installed over walls, building supports and warehouse structures. These vehicles are equipped with an advanced obstacle detection system, that allows them to progressively slow down, until stopping, in presence of an obstacle. Additional sensors enable the vehicles to scan barcodes or read RFID tags placed on unit loads. As regards data processing and task management, two software agents are adopted: a control system, continuously monitoring AGVs status and centrally planning their paths, and a traffic manager, receiving instructions from the Warehouse Management System and assigning missions to vehicles. Another possibility is allowed for mission assignment, in simple systems where only one AGV and few workstations are involved: a direct ethernet connection can be established, allowing workstations to directly communicate missions to the AGV. The same type of connection can be exploited for the direct communication between AGVs and automatic doors or conveyors, managing simple interfaces.

Company E's AGVs are small vehicles used for totes handling, that rely on natural landmarks for navigation purposes. They are supplied together with a software that communicates with both the warehouse information system and the vehicles, assigning missions and planning paths. Each vehicle can exchange data only with the central node, but it has an on-board computer used to autonomously solve the obstacle avoidance problem.

5. Discussion and conclusions

Case studies showed that AGV solutions available on the market can be effectively classified using the framework developed in this research (Table 2). Cases provided useful insights about all the dimensions of the framework. They highlighted that AGVs based on *Open* navigation paths are increasingly available on the market, but the choice between *Fixed* and *Open* navigation path mainly depends on the type of application for which the AGV is intended. Cases also showed that, even within the *Fixed* option, flexibility of vehicles is increasing. In particular, adhesive reflectors used by Company D represent a new type of artificial landmarks for laser-guided navigation, never mentioned in literature: compared with traditional reflectors, they reduce the effort needed to reconfigure the navigation system when a layout change occurs. Furthermore, from the analysed cases it seemed that the *Hybrid* navigation path option, proposed in literature, is not adopted in real applications. A possible reason, suggested by Company C and Company D, is that this type of solution would require a very expensive obstacle avoidance system onboard vehicles, whose cost is comparable with the cost of the navigation system adopted in the *Open* configuration. Therefore, if the vehicle were able to partially perform autonomous navigation, even if for mere obstacle avoidance, it could be easily configured also to do fully autonomous navigation bypassing the need to install fixed equipment, that is costly and reduces the flexibility of the whole system. As regards the remaining two dimensions of the framework, central nodes, communicating with AGVs and coordinating them, were found in four out of five AGV solutions. Two of these AGVs also have M2M capabilities, since they can directly communicate with workstations, automatic doors and conveyors, but not with other AGVs. The only case in which *Horizontal* communication and fully *Decentralised* decisions were allowed is Company A, whose AGVs are intended for factories where vehicles periodically visit a limited number of workstations, autonomously deciding which one to serve first: this context is very similar to the one described by Bottani et al. (2017), the only authors that presented this type of system in literature. Case studies also confirmed that different combinations of options on the axes are possible: for instance, *Vertical* communication can be associated with either *Centralised* or *Hybrid* decisions, depending on the presence of a computing system onboard the AGVs. Finally, it was found that the evolution of AGVs along the axes of the framework is strictly linked to Industry 4.0 principles (Barreto et al., 2017). In particular, the evolution on the Navigation path axis is connected with the Digital Twin concept: the virtual maps created by free-ranging AGVs are digital copies of the physical world, used by vehicles to navigate the warehouse. Also, the IoT paradigm is involved every time AGVs gather information through sensors and transmit them to a processing unit, while the M2M is at the basis of the advancements in the Communication axis.

This research raised from a gap resulting from the few studies on the evolution of AGVs in the landscape of Logistics 4.0. The gap was addressed through literature review and five case studies, and a three-axes classification framework was developed. The proposed framework can be used both by academics, to identify new AGV configurations that need further investigation, and by practitioners, to position their AGVs against other existing solutions. Further research could proceed with a detailed comparison among the AGVs described in this paper, considering also their technical features (e.g. speed, width, maximum load), and aiming to assess the costs and application fields of the different solutions.

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APPENDIX A

The classification reported in this appendix refers to the main solution proposed by each paper, neglecting other solutions presented as older or alternative ones.

Paper	Navigation path		
	Fixed	Hybrid	Open
Berman and Edan, 2002		X	
Farahvash and Boucher, 2004	X		
Kelly et al., 2007			X
Herrero-Pérez and Martinez-Barberá, 2008		X	
D'Andrea and Wurman, 2008	X		
Martinez-Barberá and Herrero-Pérez, 2010		X	
Reinke et al., 2013			X
Cardarelli et al., 2014		X	
Oleari et al., 2015			X
Digani et al, 2015	X		
Pinkam et al., 2016	X		
Fedorko et al., 2017			X
Bottani et al., 2017	X		

Paper	Communication		
	Vertical	Mixed	Horizontal
Berman and Edan, 2002			X
Farahvash and Boucher, 2004	X		
Kelly et al., 2007	X		
Herrero-Pérez and Martinez-Barberá, 2008		X	
D'Andrea and Wurman, 2008		X	
Martinez-Barberá and Herrero-Pérez, 2010	X		
Reinke et al., 2013	X		
Cardarelli et al., 2014	X		
Oleari et al., 2015	X		
Digani et al, 2015		X	
Pinkam et al., 2016	X		
Fedorko et al., 2017	X		
Bottani et al., 2017			X

Paper	Decision		
	Centralised	Hybrid	Decentralised
Berman and Edan, 2002			X
Farahvash and Boucher, 2004	X		
Kelly et al., 2007		X	
Herrero-Pérez and Martinez-Barberá, 2008		X	
D'Andrea and Wurman, 2008		X	
Martinez-Barberá and Herrero-Pérez, 2010		X	
Reinke et al., 2013	X		
Cardarelli et al., 2014		X	
Oleari et al., 2015	X		
Digani et al, 2015		X	
Pinkam et al., 2016	X		
Fedorko et al., 2017	X		
Bottani et al., 2017			X