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Task assignment in material handling systems and impact of Logistics 4.0: a systematic literature review

TESI DI LAUREA MAGISTRALE IN
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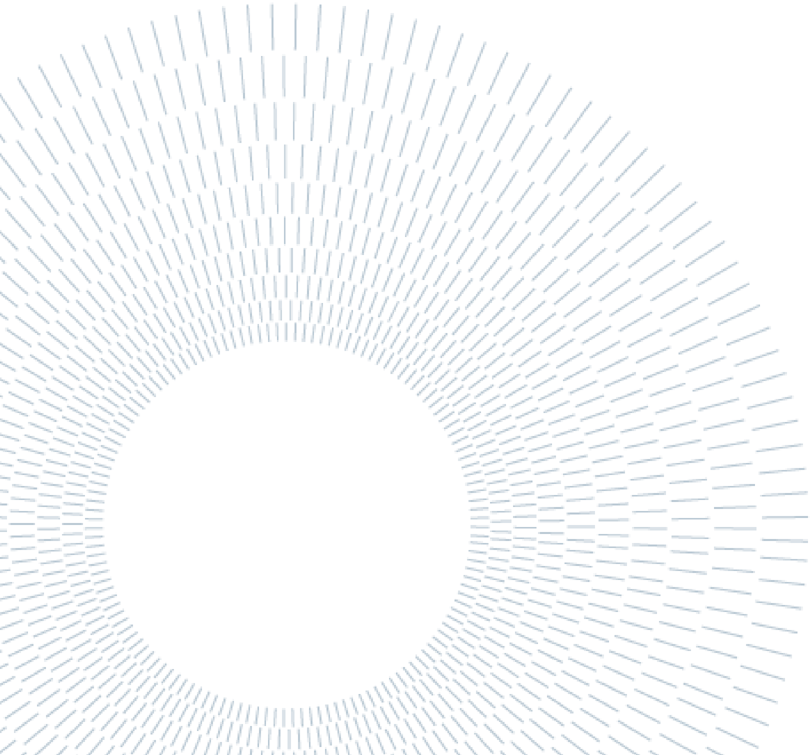


ABSTRACT

Nowadays companies find themselves in a context that can be defined as the result of the union of two phenomena.

Firstly, the transition from mass production to mass customization has forced companies to offer wider and wider ranges of products. Many manufacturing firms produce a huge number of products, each one configurable in many variants. Hence, production processes (assembly lines above all) need to be fed with an enormous amount of parts. Furthermore, the manufacturing industry is progressively facing more competition, which also involves the need of low response times and competitive prices. Material handling systems (MHSs) play a crucial role for the achievement of all these objectives, caused by a market “pull” action.

The second current phenomenon that affects companies is the technological “push”, which has now caused the fourth revolutionary wave in the industry, known as Industry 4.0. Unlike previous industrial revolutions, this time the technologies that can be exploited are many and the combined use of multiple technologies leads to a "combinational effect": the effect deriving from the simultaneous use of several levers is much greater than the sum of the single effects. From a strategic and managerial point of view this means that companies must try to be at the forefront on several fronts, to have a huge competitive advantage. Among all business processes, the MHS is certainly one of the most sensitive to this innovation.

Therefore, considering the flexibility and efficiency required and the possibility of innovation, the part feeding is essential. This Systematic Literature Review (SLR) aims first of all to identify the relevant dimensions of this process, to provide a clear framework of all the possible variables that can be encountered in the analysis of the MHS. Equally important, the second point of this thesis evaluates the impact that Logistics 4.0 has on this process.

Keywords: material handling system, intralogistics, part feeding system, task assignment, transport of parts, Industry 4.0, Logistics 4.0.

ABSTRACT IN ITALIANO

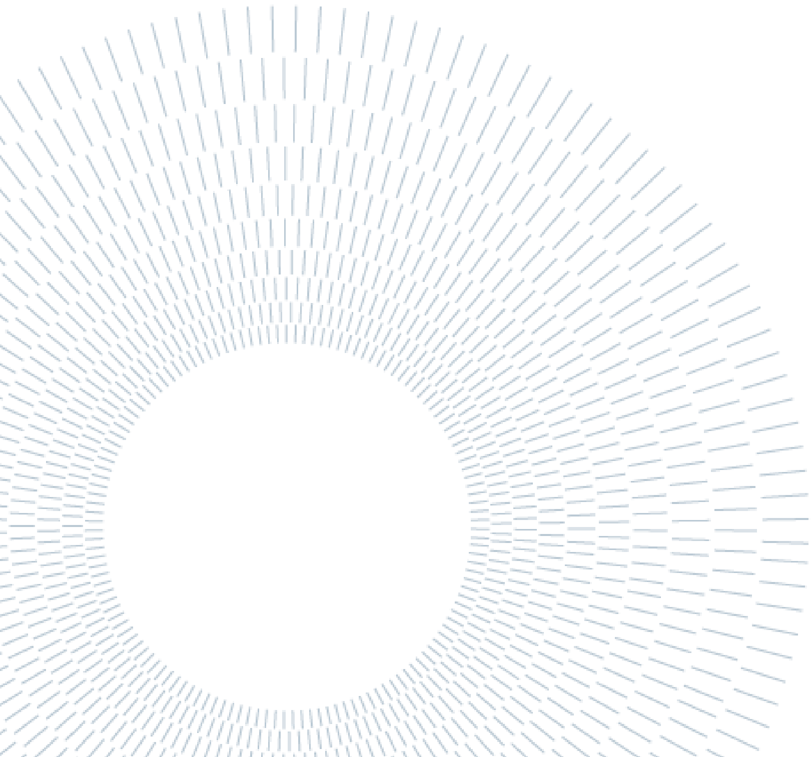
Al giorno d'oggi le aziende si trovano in un contesto che può essere definito come il risultato dell'unione di due fenomeni.

In primo luogo, la transizione dalla “mass production” alla “mass customisation” ha forzato le aziende ad offrire gamme di prodotti sempre più ampie. Di conseguenza, molte aziende manifatturiere producono un immenso numero di prodotti, che sono inoltre configurabili in diverse varianti. Dunque, i processi produttivi (maggiormente le linee di assemblaggio) necessitano di essere riforniti con un’immensa quantità di componenti. Inoltre, l’industria manifatturiera sta affrontando una competizione crescente che comporta anche la necessità di avere tempi di risposta bassi e prezzi competitivi. I sistemi di movimentazione (MHS) delle parti giocano un ruolo cruciale per il raggiungimento di tutti questi obiettivi, causati da un'azione di tipo “pull” del mercato.

Il secondo fenomeno attuale che influenza le aziende è il “push” tecnologico, che ormai ha causato la quarta ondata rivoluzionaria nell'industria, nota appunto come Industria 4.0. A differenza di quelle precedenti, questa volta le tecnologie che possono essere sfruttate sono molte e l’utilizzo combinato di queste porta ad un effetto ben maggiore di quello portato dalle singole leve. Da un punto di vista gestionale e strategico questo significa che le aziende devono provare ad essere all’avanguardia su vari fronti per avere un considerevole vantaggio competitivo. Tra tutti i processi aziendali, il MHS è sicuramente uno dei più sensibili a questa innovazione.

Considerando quindi la flessibilità e l’efficienza richieste e la possibilità di innovazione, il rifornimento delle parti è fondamentale. Questa SLR mira innanzitutto ad indentificare le dimensioni rilevanti di questo processo, per fornire un quadro chiaro di tutte le possibili variabili che si possono incontrare nell'analisi del MHS. Non meno importante, il secondo punto di questa tesi valuta l'impatto che la Logistica 4.0 ha su questo processo.

Parole chiave: sistema di movimentazione dei materiali, intralogistica, sistema di rifornimento delle parti, assegnazione delle missioni, trasporto delle parti, Industria 4.0, Logistica 4.0.



CONTENTS

1 INTRODUCTION AND RESEARCH QUESTIONS

This thesis arises from the union of two current and simultaneous phenomena: mass customization and logistics 4.0.

Winkelhaus and Grosse (2020) defined Logistics 4.0 as: “the logistical system that enables the sustainable satisfaction of individualized customer demands without an increase in costs and supports this development in industry and trade using digital technologies”.

Although the theme of Industry 4.0 is now known and no longer a novelty, it is interesting to describe it briefly. The term "Industry 4.0" has Germanic origins, in fact it was used for the first time during the "Hannover Messe" of 2011, the world's leading industrial technology show, a reference point for industrial innovation for over a century in which all the new cutting-edge energy and industrial technologies come together. It was at this event that three-leading figure, namely Henning Kagermann, Wolf-Dieter Lukas and Wolfgang Wahlster, presented their work entitled "Industry 4.0: Internet". The term Industry 4.0 is the propensity of today's industrial automation to insert some new production technologies to improve working conditions, create new business models, increase plant productivity, and improve product quality.

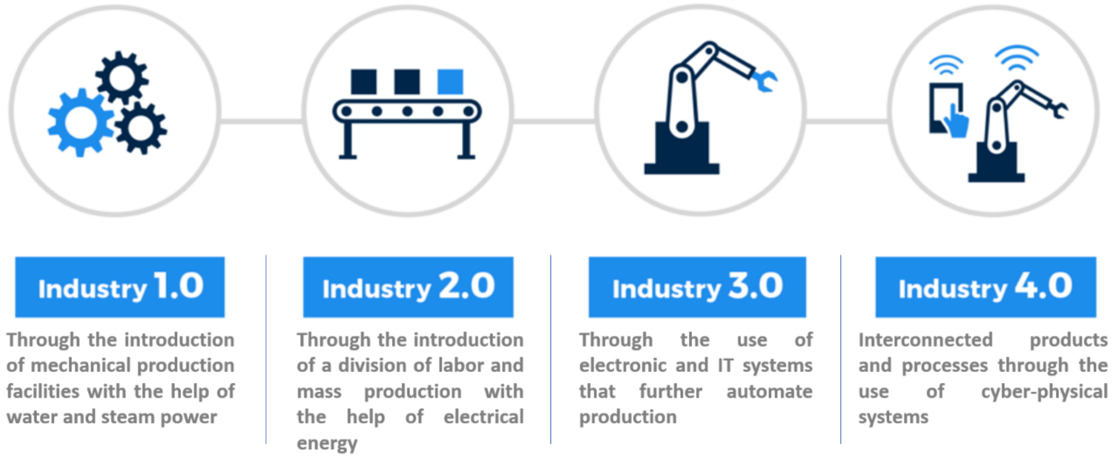
The number 4.0 symbolizes the fact that this is the fourth revolutionary wave that has occurred in the industrial world, since the famous industrial revolution. The first discovery that caused a huge change in the sector was the introduction of steam-powered machines or fossil fuels. This discovery was so powerful that it triggered the first industrial revolution. The use of these machines has profoundly changed the production methods of the factories and gave rise to the first form of mechanization of the production process.

With the spread of electricity and the brilliant idea of division of labour, it was possible to significantly increase production volumes in factories. This is the heart of the second industrial revolution, which is set starting from the year 1870, with the birth of the first assembly line.

From 1969 onwards, with the appearance of the first programmable logic controller (PLC), we can speak of the third industrial revolution, characterized by the large-scale use of electricity and the consequent development of IT systems in industry, which together allowed for the automation of production.

Finally, we come to the fourth industrial revolution, which differs from the previous one because it does not aim only at the automation of processes, but at an interconnection between the physical and virtual world. The heart of industry 4.0 is the cyber-physical system, which consists of an unlimited integrated system, in which data and information can be exchanged in real time between various subjects, and continuously. These elements create an intelligent environment capable of responding autonomously and promptly to any external situation.

Figure 1 briefly shows the four industrial revolutions.



Through the introduction of mechanical production facilities with the help of water and steam power

Through the introduction of a division of labor and mass production with the help of electrical energy

Through the use of electronic and IT systems that further automate production

Interconnected products and processes through the use of cyber-physical systems

Figure 1: The four industrial revolutions

Industry 4.0 involves the use of all the following technologies: Big Data, Internet of Things, Automation Robotics, Cloud Computing & Cyber Security, Human Machine Interfaces and Additive Manufacturing. Unlike previous industrial revolutions, the technologies that can be exploited are many and the combined use of multiple technologies leads to a total result that is much higher than the sum of the effect of the single technologies, and this phenomenon is known as the "combinational effect". From a strategic and managerial point of view this leads to a consequence: companies must try to be at the forefront on several fronts, in order to have a huge competitive advantage, otherwise, vice versa, the disadvantage with the others will also be enormous. The digitization that companies are experiencing, as a result, is something that cannot be ignored, but represents an important opportunity for an improvement in the world economy and for society.

The possibility of being able to rely on a virtual world to make simulations and prototypes has given companies the opportunity to make these processes faster and cheaper. The immediate consequence of this phenomenon is a reduction in time to market, which is defined as the length of time it takes from a product being conceived until its being available for sale.

This phenomenon brings with it advantages, such as reducing the risk of launching a new product, because it will remain less time on the market (think that the Ford Model T was produced for 19 years, from 1908 to 1927). On the other hand, this low time to market, resulting in a rapid change of products on the market, forces companies to have a reconfigurable production system, flexible enough to be able to follow this high turnover or products.

Actually, the context in which we find ourselves today, and therefore the reason why the theme of this thesis is so relevant, is not only the consequence of a push type innovation. In other words, the need to have a flexible production system is not only the result of years and years of continuous discoveries and innovations that then "pushed the market" in this direction.

Kousi et al. (2019) stated: “[…] the transition from mass production to mass customisation has indicated the need of deploying flexible manufacturing systems able to handle multiple product variants. Given the existence of multiple assembly components, faults in the component’s feeding mechanisms and inventory control have been established as a major cause of failures during the assembly”. Many solutions have been proposed but most of them are based on manual effort creating failures due to human errors and lack of real-time monitoring of the assembly line’s needs.

Manufacturing industry is progressively facing more competition, resulting in a wide range of products to offer. Therefore, single manufacturing firms produce a huge number of products, each one configurable in many variants. Hence, production processes (assembly lines above all) need to be fed with an enormous amount of parts.

It may be interesting and useful to understand how this market demand (known as “mass customization”), which has such an impact on the production processes of companies, has evolved to this point.

The evolution of manufacturing has passed through various phases, which are described below and which are represented in the Figure 2, on a two-dimensional plane that has the variety of products on the horizontal axis and the production volume on the vertical axis (which reflects the market demand).

Starting in 1850, the second half of the nineteenth century was characterized by the "craft production", i.e. the production of a few (if not single) pieces at a time, highly customized.

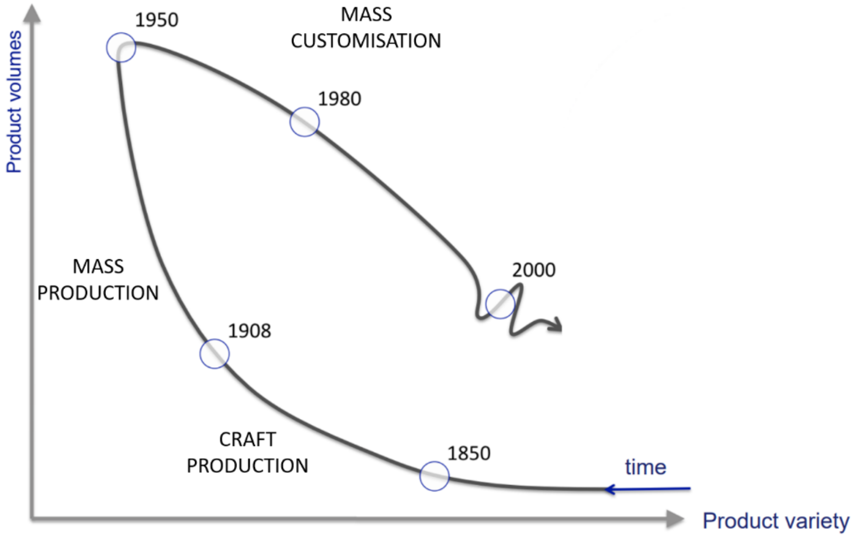


Figure 2: Demand evolution

From 1908 onwards, there was the "mass production". Considering the Ford case: the market was prime supply, the cost of the car was deliberately low to allow most people to be able to buy the product. Production was then in large volumes. To this aim, however, a complete standardization was necessary, resulting in the idea of division of labour: dividing the process into activities as limited as possible so that workers became specialized in this and as a result, efficiency and productivity increased. This however excluded the possibility of offering more models and variants.

In the second half of the century, however, the "mass customization" appeared. Volumes remained relatively high but at the same time the variant grown. This because after the Second World War people became more affluent, so much so that they could afford to pay more for more personalized products.

This concludes the reasoning aimed at contextualizing the underlying reason of this SLR in today's world.

Therefore, considering the flexibility and efficiency required and the possibility of innovation, the part feeding is essential (the cost can be decreased by 10 –30 per cent in case a good Material Handling System (MHS) is provided).

Kilic and Durmusoglu (2015) pointed out that the part feeding system can be considered as the union of three main components which cannot be considered as independent: storage of parts, transport of parts and feeding policy (Figure 3).

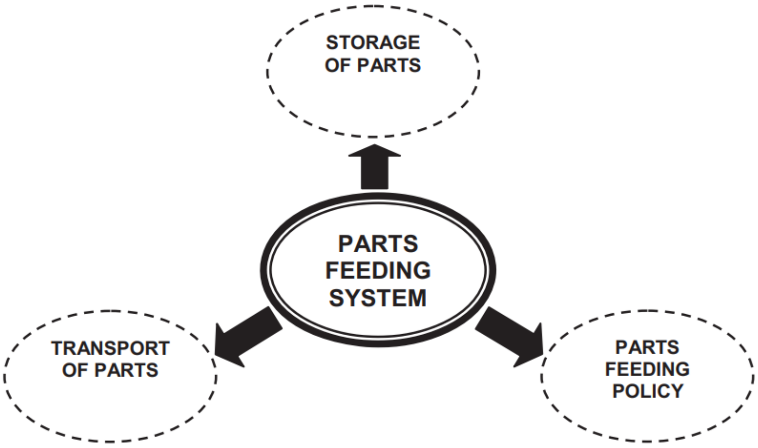


Figure 3: Parts feeding system structure (Kilic and Durmusoglu, 2015)

This research must focus on one of these aspects, as it cannot deal with them all given the very vast topic. In the literature, few articles have deepened the theme of transport of part, compared to the other two macro areas.

Beyond this, transport of parts is crucial for companies. Although it can be compared to the cardiovascular system in a living organism, as it allows the flow of materials and components, material handling is a process that does not add value to the finished product. Nevertheless, a substantial portion of the whole production time, work-in-process (WIP) and use factory space depend on it. In other words, it is an “indirect” (if the cost for the equipment is excluded from this reasoning) fundamental component of the production cost.

Manufacturing lead time (MLT) is the total time required to process the product in the manufacturing plant. In a typical manufacturing environment, MLT is much greater than the Actual Processing Time (APT). The APT, which comprises the set-up time and processing time, could be a small fraction of the MLT, due to all those activities such as loading and unloading, transport, waiting and queuing, that constitute the rest of the MLT (Veeravalli, Rajesh and Viswanadhams, 2002).

It is found that between 13% and 30% of production costs can be attributed to material handling (Singh and Tiwari, 2004). This is one of the reasons why material handling is so important, since the production costs must be as low as possible not only for a matter of profit, but also for a "survival" discourse. Babiceanu, Chen and Sturges (2004), among others, suggest that: “To be competitive, manufacturing, like any other sector of the economy, should continuously adapt to the changing conditions existing in the market. Increased global competition is forcing manufacturing companies to reduce response time and always to offer competitive prices for their products. The greater variety of products, the possible large fluctuations in demand, the shorter life cycle of the products expressed by an increased frequency of introduction of new products, and the increased customer expectations in terms of quality and delivery time are the challenges that manufacturing companies have to deal with to remain competitive and survive in the market. Besides the above market-based challenges, to remain competitive, manufacturing companies also need constantly to adapt to newly developed processes and technologies and to rapidly changing environmental protection regulations”.

This SLR is motivated by such background and aims to investigate the following Research Questions (RQs):

RQ1. *What are the relevant dimensions used to describe the task assignment process for a fleet of vehicles feeding production systems?*

RQ2. *How does the implementation of Logistics 4.0 principles affect the task assignment?*

2 RESEARCH METHODOLOGY

During a review of the literature the researcher both maps and assesses the relevant intellectual territory in order to specify a research question which will further develop the knowledge base. Systematic reviews differ from traditional narrative reviews by adopting a replicable, scientific, and transparent process, in other words a detailed and clear methodology that can be replicated. In order to achieve this aim, an audit trail of the reviewers' decisions, procedures and conclusions is needed.

For this reason, it was decided to follow clear and tested steps. To outline these steps, two key publications were considered. First, Tranfield et al. (2003) drew on previous SLR guidelines to provide the adaptation of SLRs to the management field. Second, Durach et al. (2017), in which a new paradigm for SLRs in the supply chain domain is proposed. This approach is based on both best practice and the unique attributes of doing supply chain management research, since it is based on the assumption that each discipline has idiosyncrasies in its research that influence the retrieval, selection, and synthesis of relevant literature. Furthermore, Durach et al. (2017) is based on four main publications: Mulrow (1987), Tranfield et al. (2003), Cochrane Collaboration (2011) and Campbell Collaboration (2016).

So, the steps identified are the result of numerous specific articles on the SLR and Table 1 shows an overview of the six SLR steps, with each step linked to the four references.

Guidelines for Conducting Systematic Literature Reviews in Supply Chain Management

Common SLR Steps	SLR steps for SCM research				Description of Steps in General SLR Guidelines	Description of Steps in an SCM Review
	Mulrow (1987)	Cochrane Collaboration (2011)	Campbell Collaboration (2016)	Tranfield et al. (2003)		
Step 1: Define research question	x	x	x	x	• Justify review in terms of timeliness and relevance • Highlight contribution of SLR	• Develop an initial theoretical framework regarding the phenomenon under study (based on prior knowledge and scoping studies) with the aim of refining it in light of the SLR literature o Framework must specify limitations regarding units of analysis (e.g., dyad vs. ultimate supply chain), study contexts (e.g., culture, industry, time), and construct definitions (e.g., firm resilience vs. supply chain resilience)
Step 2: Determine required characteristics of primary studies	x	x	x	x	• Craft inclusion and/or exclusion criteria o for example, research method, study focus, outlet, and language used	• Develop criteria for determining whether a publication can provide information regarding the theoretical framework o Assess contribution to initial theoretical framework, including units of analysis, study contexts, definitions, and operationalization of constructs
		x	x	x		

(continued)

TABLE 1 (continued)

Common SLR Steps	SLR steps for SCM research				Description of Steps in General SLR Guidelines	Description of Steps in an SCM Review
	Mulrow (1987)	Cochrane Collaboration (2011)	Campbell Collaboration (2016)	Tranfield et al. (2003)		
Step 3: Retrieve sample of potentially relevant literature ("baseline sample")					• Determine search procedures (e.g., database search, cross-referencing) • Define and apply keywords to retrieve a preliminary sample of primary studies	• Identify literature through structured and rigorous searches (see the next section for a discussion on potential biases in this step) o Multiple searches may be needed to identify literature on all aspects of the theoretical framework o Consider the breadth of definitions and terminologies in SCM research when constructing search terms
Step 4: Select pertinent literature ("synthesis sample")	x	x		x	• Apply inclusion and/or exclusion criteria	• Conduct theoretically driven selection of literature to identify relevant studies according to inclusion/exclusion criteria (see the next section for a discussion on potential biases in this step) • Conduct a detailed relevance test that goes beyond what is stated in titles and abstracts
Step 5: Synthesize literature	x	x	x	x	• Apply coding schemes to extract pertinent information from the literature	• Develop two data extraction structures on the basis of aspects of the initial theoretical framework

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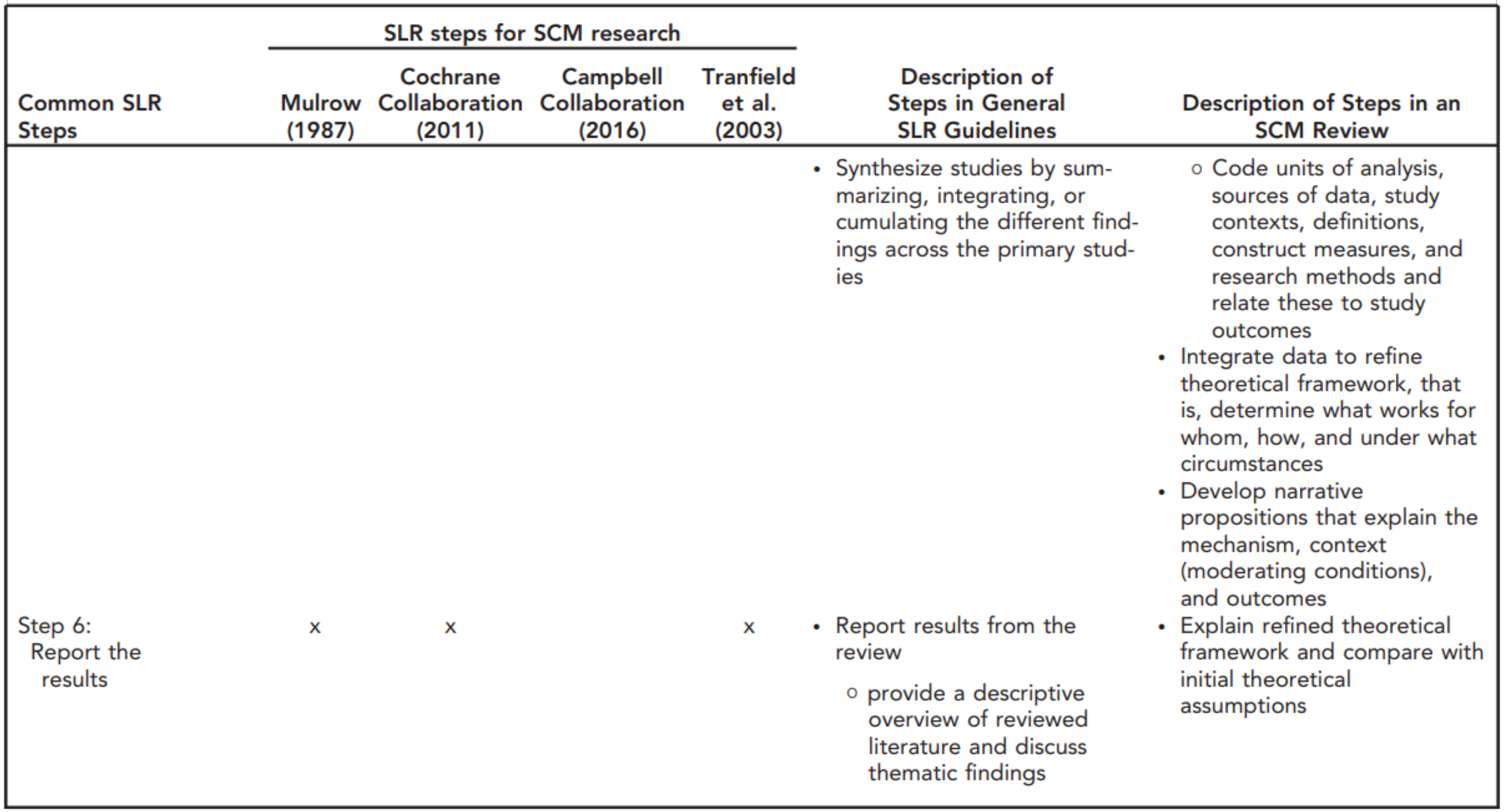


Common SLR Steps	SLR steps for SCM research				Description of Steps in General SLR Guidelines	Description of Steps in an SCM Review
	Mulrow (1987)	Cochrane Collaboration (2011)	Campbell Collaboration (2016)	Tranfield et al. (2003)		
					• Synthesize studies by summarizing, integrating, or cumulating the different findings across the primary studies	○ Code units of analysis, sources of data, study contexts, definitions, construct measures, and research methods and relate these to study outcomes • Integrate data to refine theoretical framework, that is, determine what works for whom, how, and under what circumstances • Develop narrative propositions that explain the mechanism, context (moderating conditions), and outcomes
Step 6: Report the results	x	x		x	• Report results from the review ○ provide a descriptive overview of reviewed literature and discuss thematic findings	• Explain refined theoretical framework and compare with initial theoretical assumptions

Table 1: SLR steps

Figure 4 graphically shows the methodology followed:

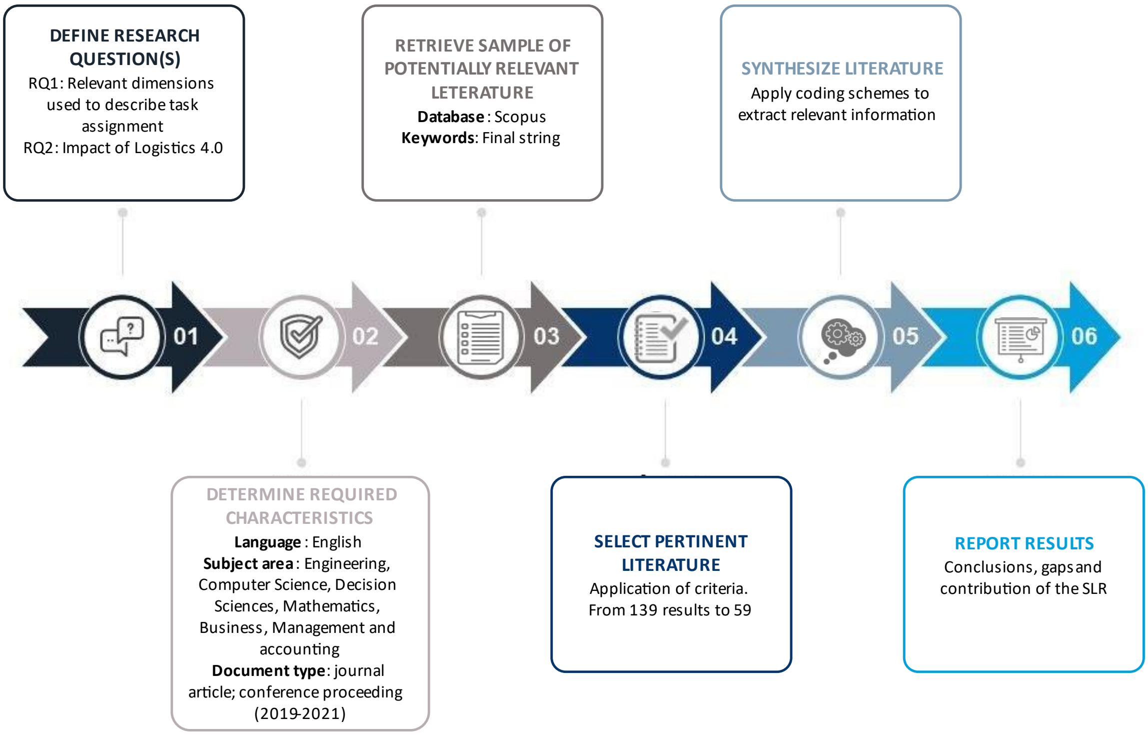


Figure 4: SLR methodology

Step one in SLR should start with taking a theoretical lens on the phenomenon of interest. This was discussed in the introduction and the research questions that outline the field of interest are shown below:

RQ1. *What are the relevant dimensions used to describe the task assignment process for a fleet of vehicles feeding production systems?*

RQ2. *How does the implementation of Logistics 4.0 principles affect the task assignment?*

The second step provided by Durach et al. (2017) consists in the definition of the characteristics of the primary study, by crafting inclusion/exclusion criteria. These criteria commonly reflect various aspects of the research purpose and research question(s) and focus on the content and quality of the primary studies (Mulrow, 1987; Tranfield et al., 2003; Cochrane Collaboration, 2011; Campbell Collaboration, 2016;). The chosen criteria depend on the desire to base reviews on the best-quality evidence. Thereby, the research was carried out on Scopus and the criteria chosen to select the results were the following:

- Language: limited to English.
- Subject area: Engineering, Computer Science, Decision Sciences, Mathematics, Business, Management, and accounting. The objective of the SLR and the defined RQs are of a managerial nature and also fall within the decision sciences. On the other hand, to be sure not to exclude important contributions, the areas of engineering and mathematics have also been included, although these treat the problem from a more technical (in the first case) and a more theoretical point of view, with optimization models (in the second case). Other subjects (i.e., chemistry, astronomy, etc.) have been excluded as they are far from the field of research.
- Source type: limited to journal (this choice was driven by the desire to include only high-quality, peer-reviewed publications).

Actually, in this way some recent scientific contributions would have been excluded, for instance conference proceedings not yet published on journals. As a consequence of this, it has been decided to carry out two searches with the same filters, except for the filter on the source type, which instead is replaced by the following two:

- Document type: Conference Proceedings.
- Year: 2019, 2020, 2021.

The second research guarantees the inclusion of publications that may be useful, but only the most recent ones, since conference proceedings dating back more than three years ago do not carry with them the advantage for which it was decided to include them.

According to Durach et al. (2017), the third step of an SLR is to retrieve a "baseline sample" of potentially relevant literature. The general guidelines suggest further that the search applies a combination of keywords, which are based on the research purpose, research question(s) (step 1), and inclusion/exclusion criteria (step 2).

The query string used for this SLR is the following:

(scheduling OR "dispatching rul*" OR "task assignment") AND
("material handling equipment" OR vehicle* OR robot* OR truck* OR forklift*) AND
("material supply" OR "part feeding" OR "factory logistics" OR "plant logistics" OR intralogistics OR "part logistics" OR "transport* of part" OR ("material handling" AND (plant OR factory OR "shop floor" OR assembly)))

First, the sources of the keywords used are shown in Table 2:

Table 2: Sources of keywords

	Moretti et al. (2021)	Dong and Jin (2021)	Schmid and Limére (2019)	Kousi et al. (2019)	Boysen et al. (2015)	Kilic and Durmusoglu (2015)
Keywords chosen by the authors	- Part feeding - Factory logistics - Mobile robot - Design trade-of - Queuing network	- Logistics - Shuttle-based storage and retrieval system - Travel time model - Storage policy - Shuttle dispatching rule	- Assembly systems - Logistics - Decision support system - Facility planning - Mass customisation - Problem structuring	- Material supply operations - Real-time scheduling - Discrete event simulation - Autonomous mobile robots - Service-oriented architecture	- Automotive industry - Just-in-time - Part logistics - Survey	- Assembly line - Feeding policy - Hybrid feeding

Among these, the ones considered relevant and consistent with the context were: scheduling, dispatching rule, material supply, part feeding, factory logistics, part logistics.

"Plant logistics", "transport of part" and "material handling" have also been added to the keywords listed above (these are not present as keywords suggested in Table 2, but are expressions found in the article by Kilic and Durmusoglu (2015)).

This was therefore the identification of the starting keywords. The next step consisted in organizing them logically and add any synonyms where possible. The attempts made to generate the search string are shown below, with the progressive modifications justified:

a. The initial idea was to organize the string into three blocks that had to coexist (therefore joined with the logical AND operator). The first describes the objective of the research, the second contextualizes it in the problem or environment considered, the third further tightens the context. The result of this reasoning was the following query:

(scheduling OR “feeding polic*” OR “dispatching rul*” OR “task assignment”) AND
(“part feeding” OR “factory logistics” OR “plant logistics” OR “facility planning” OR intralogistics OR “part logistics”) AND
(assembly)

Results: 51 documents.

There were two main problems with this string. First, there was not enough focus on the transport of the parts; second, the third block ("assembly") involves a non-trivial consequence: in this way the research focused on the assembly systems, but the problem of part feeding does not concern only those, it can also affect other processes (for instance manufacturing operations, which must be supplied too). A consideration can be made from this point of view. Of all the processes, assembly is certainly the one that involves more parts and components, so the problem of part feeding becomes more complex at this point. However, it would not be correct to restrict the field of research to just the assembly lines.

As last consideration, "facility planning" is a too vague expression.

b. Made these considerations, the second string was:

(scheduling OR "dispatching rul*" OR "task assignment") AND
("material handling" OR "part feeding" OR "factory logistics" OR "plant logistics" OR intralogistics OR "part logistics")

Results: 1544 documents.

The changes were: exclusion of “feeding polic*" in the first block, exclusion of “facility planning” in the second block and addition of “material handling” (to bring the target on the transport of part as explained above. The term derives from Kilic and Durmusoglu (2015), in which it is explained that: “The transport of parts can be regarded under material handling system. […] Besides the selection of the equipment, the movement and routing of the vehicles are also essential during the parts feeding process. Hence, MHE selection and MHE routing are determined as the two subcomponents of the transport of parts”).

c. The following query was an attempt to try to impose “transport of part” or “material handling” as a third block.

   (scheduling OR "dispatching rul*" OR "task assignment") AND ("part feeding" OR "factory logistics" OR "plant logistics" OR intralogistics OR "part logistics") AND ("transport of parts" OR “material handling”)

   Results: 4 documents.

   This research has shown that “transport of parts” and “material handling” cannot constitute a separate logical block that coexists with the previous ones. However, it makes sense to use these two expressions as synonyms, as suggested by Kilic and Durmusoglu (2015).

d. At this point “transport of part” and “material handling” were added in the second block.

   (scheduling OR "dispatching rul*" OR "task assignment") AND ("part feeding" OR "factory logistics" OR "plant logistics" OR intralogistics OR "part logistics" OR “transport of part" OR "material handling")

   Results: 1544 documents.

   Among the results obtained there were articles that do not talk about the subject concerned (for example truck scheduling). Consequently, it was necessary to contextualize the material handling within the factory. In addition, documents appeared related to scheduling but not related to the transport of parts (e.g., scheduling of production activities).

e. To take into account the consideration just made, the new query added the AND operator to "material handling", with keywords related to the context in which this research is grounded (i.e., assembly) which are linked with the OR operator since they are equivalent in meaning. Furthermore, to restrict the results to only documents that speak of scheduling from a transport point of view, a further block has been inserted after the first, linked to the others by the AND operator, containing all the terms that allow to link the two concepts.

(scheduling OR "dispatching rul*" OR "task assignment") AND
("material handling equipment" OR vehicle* OR robot* OR truck* OR forklift*) AND
("material supply" OR "part feeding" OR "factory logistics" OR "plant logistics" OR intralogistics OR "part logistics" OR "transport* of part" OR ("material handling" AND (plant OR factory OR "shop floor" OR assembly)))

Results: 244 documents.

The search query consisted of three logical blocks that must coexist as they are all essential, hence they are linked by the Boolean AND operator. The first block proposes alternative ways (related by the OR operator) to refer to the main objective of the research: the organization. The second block aims to contextualize the scheduling in activities that involve the transport and movement of parts, indeed only the documents that mention typical vehicles for the movement of objects in the factory were selected. Finally, there is the third block, which restricts the results to only those dealing with the area of interest, in fact different alternatives to refer to this are proposed and interspersed with the OR operator. In particular, there is still "material handling" but unlike the previous block, here it is not followed by "equipment" because the focus is the activity, not the tools (it has been contextualized through the AND operator to a set of alternatives that refer to the interested environment).

To minimize the risk of excluding relevant literature, one of the most commonly used digital databases was utilized: Scopus.

In the fourth step, the inclusion/exclusion criteria (step 2) were applied to reduce the sample of primary studies to a subset, which can be referred to as the "synthesis sample." Hypothetically, this sample should include all relevant studies and excludes irrelevant ones. Specific guidelines are lacking regarding where (i.e., title, abstract, keywords, full text) the inclusion/exclusion criteria need to be applied (Mulrow, 1987; Tranfield et al., 2003; Cochrane Collaboration, 2011; Campbell Collaboration, 2016;). Thereby, the filters have been applied to keywords/title/ abstract. To conclude, the final strings used, combined with the filters, led to the identification of 139 documents (131 journal articles and 8 conference paper).

The final part of this step consisted in filtering the documents found after reading the title, the abstract and the full text, verifying the consistency with the theme of the SLR. Table 3 provides a screening after each filtering:

Table 3: SLR methodology screenings

	Research output	Filter by titles	Filter by abstract	Filter by full text
Results after each phase	139	101	71	59

The title filter excluded documents from which it was understood that the theme was not inherent to this SLR (an example among many is the article: "*An investigation into yard allocation for outbound containers*"). The same logic was applied during the abstract filter and finally the full text filter.

The fifth step is concerned with study synthesis, applying coding schemes to extract relevant information from the literature.

Finally, the sixth step involves the results of the SLR, identified gaps and conclusions.

3 LITERATURE REVIEW RESULTS

The initial sample of 139 articles can be classified depending on the research area.

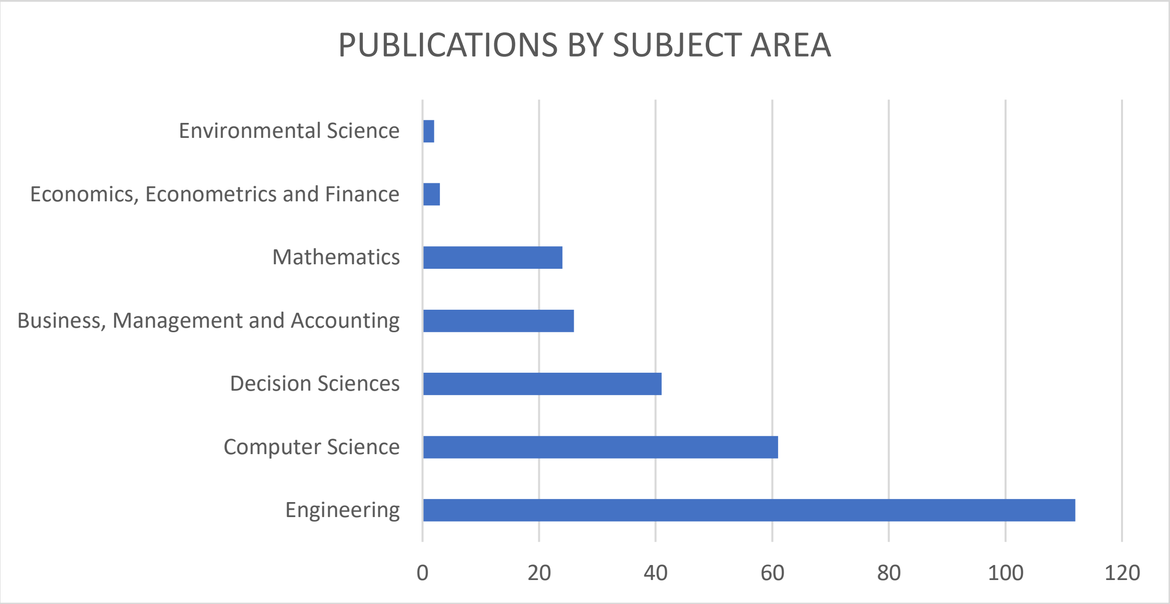


Figure 5: Classification of publications by subject area

Figure 5 provides a classification of these articles considering seven subject areas. This classification shows that the majority are on engineering, while computer and decisions sciences and mathematics highlight the importance of computational methods related to the design of MHSs. Furthermore, it is possible to observe that, in addition to the subjects specified in the research, some articles also fall into subjects such as environmental science, supporting the fact that concerns about environmental degradation and fossil fuel depletion are leading to an energy-aware manufacturing in general, and material handling processes in factories and warehouses has a relevant impact on the plant's environmental impact. The distribution shows that the design and operation problems of logistics systems in production and manufacturing are multidisciplinary problems, where not only technological but also environmental and other aspects must be taken into consideration.

As Figure 6 proves, the optimization of in-plant logistics has been researched in the past 40 years. The first articles in this field were published in the early 80’s and then the number of published papers has been increased, especially in the last five years (23 articles were published from 2017 to 2021). This shows the growing interest in this research field. Moreover, from 2010 onwards every year there have been publications (which is not true before).

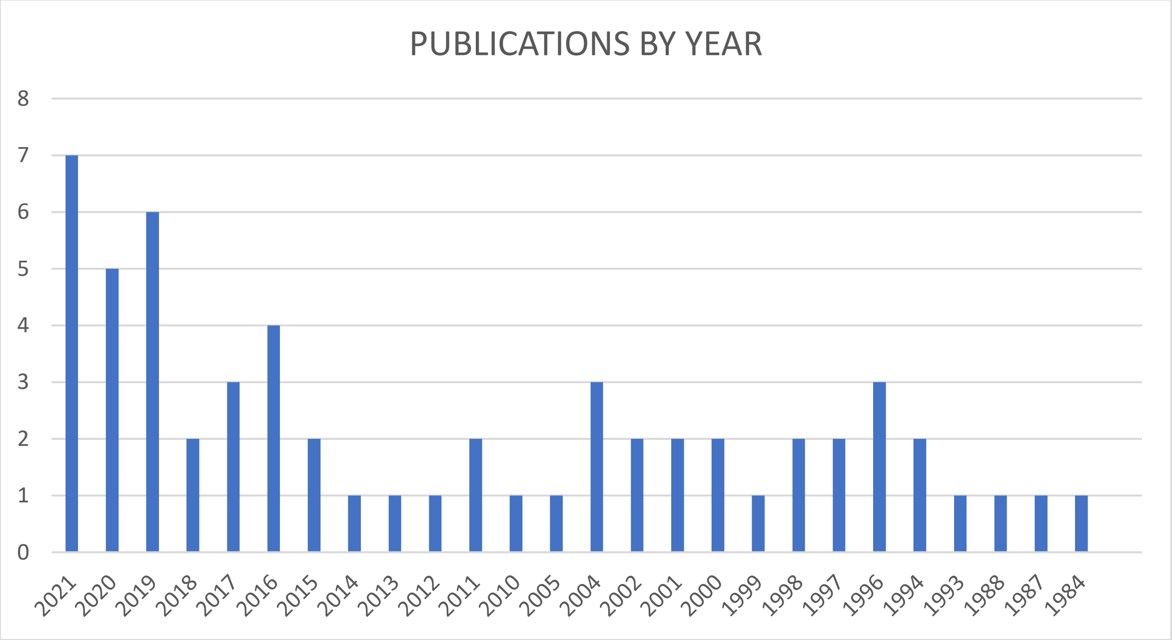


Figure 6: Classification of publications by year

4 RQ1: RELEVANT DIMENSIONS

4.1. PROBLEM DEFINITION

Nielsen et al. (2015) stated that multiple-part feeding is a non-value adding manufacturing task and quite often disruptive for production workers. Furthermore, when the workers forget to fill the feeders, this may lead to stopping the production lines. A strategy that can reduce the dependence on human intervention for the part-feeding tasks is using autonomous mobile robots instead of humans, which make multiple-part feeding tasks more flexible and pave a suitable way for developing and implementing cloud-based manufacturing models.

Rivas and Xirgo (2019) argued that transportation to solve intralogistics is becoming as complex as managing transportation in road logistics. Considering that it takes place in structured environments, automation is easier. As vehicles increase the degree of autonomy, transport systems inside those facilities look more like transport systems in urban areas.

The possibility to automate the MHS is undoubtedly seen as an advantage by all the authors of the articles read. However, they also agree that this complicates the problem, due to the increasing variables to be taken into account.

The optimal design and schedule of Automated Material Handling Systems (AMHSs) depend on several factors. Based on the reading of the articles, it is possible to generalize the various scenarios in a single common description of the problem that the MHS has to solve.

Usually, a set of vehicles is responsible for the transport of parts or components between either a warehouse and a production/assembly station, or a supermarket and a production/assembly station. In order to keep workstations well supplied, many manufacturers use so-called just-in-time supermarkets, that are, decentralized logistics areas on the shop floor, where parts are intermediately stored to then be brought to the workstation in small lots (Emde and Gendreau (2017)).

The fleet can consist of one or more vehicles, which can be homogeneous or heterogeneous in terms of load capacity (that can be considered in the suggested approach or not), kinematic characteristics (i.e., maximum speed) and functions performed.

Another aspect of the problem is the material planning side. The materials can be unloaded to the buffers of the lines when the material levels at the buffers are lower or equal to an established minimum level, or following a predefined timetable, or on request. This, as well as the frequency with which other decisions explained below are made, makes the approach static or dynamic.

In any case, whether the solution is static or dynamic, there is a time window for material supply.

Consequently, the maximum supply quantity depends on both the limitation of storage capacity at the buffers and the carrying capacity of the robot, and the frequency of supply. This makes the robot task scheduling more practical if these variables are taken into account, but at the same time more complicated.

Moreover, each vehicle can either perform one single job during a mission, or more (hence, visit more than one workstation during a trip). Another option that can be taken into consideration is the possibility to perform transfers (graphically showed in Figure 7).

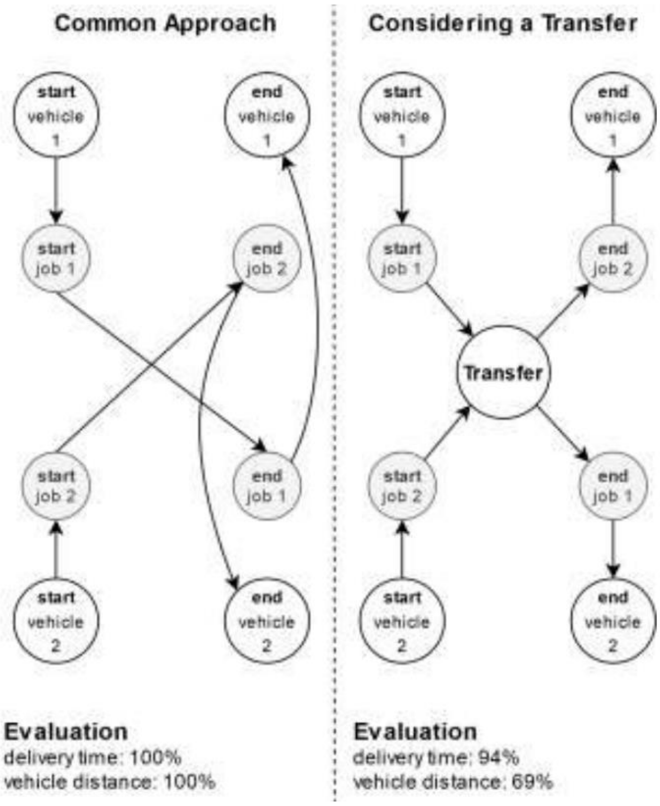


Figure 7: A basic example of dynamic transfers from simulation (Boden, Rank and Schmidt, 2020)

The concept of dynamic transfers allows the vehicles of a MHS to exchange transport carriers among each other multiple times during transport execution. This concept has been investigated in just few articles, so it is not possible to consider it a dimension used to describe and classify the part feeding problem. Nevertheless, it represents a real possibility that can be encountered in a real scenario.

According to Boden, Rank and Schmidt (2020), enabling vehicles to exchange transport carriers during the transport process dynamically, depending on the current system state and not statically predefined offers the potential to integrate additional functionalities that can increase system flexibility. Generating a schedule considering transfers is challenging, since the generalized problem is also NP-hard to solve. Exact approaches like Branch and Cut or standard solvers are utilized to generate solutions for small problem instances with up to 4 transport jobs. To investigate more extensive problem instances, approximate techniques based on Local Search (like Large Neighborhood Search or ALNS), metaheuristics (like Genetic Algorithms) are conventional. By applying the algorithms to static test cases and real transport systems, it was found that the use of transfers could lead to improvements in fleet efficiency, up to about 10%. The level of improvement depends on the characteristics of the transport system. A comprehensive investigation of the influencing factors is still pending. A comprehensive investigation of the real-time capability required for Automated Guided Vehicles (AGVs) operation is also still outstanding.

This is the scenario, described in a general way. Regarding the approaches used, they may differ according to the objective to be achieved, the problem actually solved, and the solution method used.

All the dimensions that have a significant impact on the articles read, both concerning the scenario and the proposed approach, are dealt with in more detail in the next paragraph.

4.2. RESULTS

4.2.1. OBJECTIVES

Kozan (2000) pointed out that there are several possible objective functions for the problem. These include minimising distance, minimising traveling time, minimising the number of vehicles and minimising total cost. In addition to these, three other possible objectives were found in the articles read.

Cecchi et al., 2021, focusing on the routing problem, evaluated the performance of their approach looking at the safeness and the scalability. However, these indicators turned out to be very rare in the articles read.

The main goal of some authors was to minimise both earliness and tardiness, since the first one results in vehicles waiting and the latter one causes temporary part storages in the shop floor. This is significantly important in satisfying both the expected overall takt time and production cost. To overcome such a challenge, also an optimal dispatch time of AGVs including both start time of operations for jobs at each machine in production stages and precedence relation constraints is required (Yao et al., 2020).

A good reasoning about the last possible goal is provided by Lee et al., 2021, as they argue that concerns about environmental degradation and fossil fuel depletion have led to the advent of energy-aware manufacturing and material handling processes in factories and warehouses. In accordance with this statement, mainly in recent years, several authors proposed the minimisation of energy consumption.

It is important to underline how these different objectives are interconnected. According to Zhou and Fei (2021): "the energy consumption of mobile robots mainly occurs during transportation. Therefore, it is critical to restrict the traveling distances, which are mainly determined by the limitation of the robots' loading capacity and the time window for the material distribution". This shows a clear link between travel distance and energy consumption, and also the role of the constraints related to load capacity and time windows (which are not always taken into consideration, in fact this is another dimension to distinguish various approaches). Another example is the link between the distance travelled and the time required, which is also evident.

4.2.2. CONSTRAINTS

Another relevant variable of the problem is the set of constraints considered. Actually, it does not represent a dimension to classify different scenarios or solutions. Rather, it is a fundamental property of the solutions presented as it determines their applicability in real contexts.

Zhou et al. (2012), classified constraints into three groups: processing time window constraints, robot capacity constraints and machine availability constraints.

- PROCESSING TIME WINDOW CONSTRAINTS: they are associated to machines and ensure that the processing time of all parts on each machine must be within its corresponding time window. This constraint imposes very concise timing for vehicle scheduling.
- ROBOT CAPACITY CONSTRAINTS: they guarantee that there is no conflict in the use of the robot between any pair of moves at any time.
- MACHINE AVAILABILITY CONSTRAINTS: they guarantee that there is no conflict in the use of any machine between any pair of parts at any time. It means that the robot cannot load any loaded machine or unload any empty machine.

While the third is more obvious, the first two mark a clear difference between solutions that take them into account or not, making them more or less usable. A further category of constraints has been found in the articles read:

- SINGLE/MULTIPLE LOAD CAPACITY: it does not really impose constraints on the applicability of a solution. Rather, it makes a clear distinction between those solutions that are allowed to use a single vehicle to visit multiple stations during a mission (and thus perform multiple deliveries in a single mission), and those in which the robot must go back after visiting each station.

4.2.3. FLEET CAPACITY

Capacity planning is one of the major factors of an AMHS design. Generally, surplus capacity of AMHS cannot increase the production throughput nor the return on investment (ROI). Furthermore, economic reasons and the fact that too many vehicles may cause congestion problems are clear reasons to avoid overestimation. On the other hand, if AMHS capacity is insufficient, the throughput will be impacted seriously. Tu, Lu and Lee (2013) explained this concept, also showing graphically the relationship between throughput and capacity (Figure 8). Regarding the impact on the cycle time of products, surplus capacity of AMHS can reduce cycle time. However, the shortest cycle time on a given WIP level is fixed, no matter whether the capacity of AMHS increases or not.

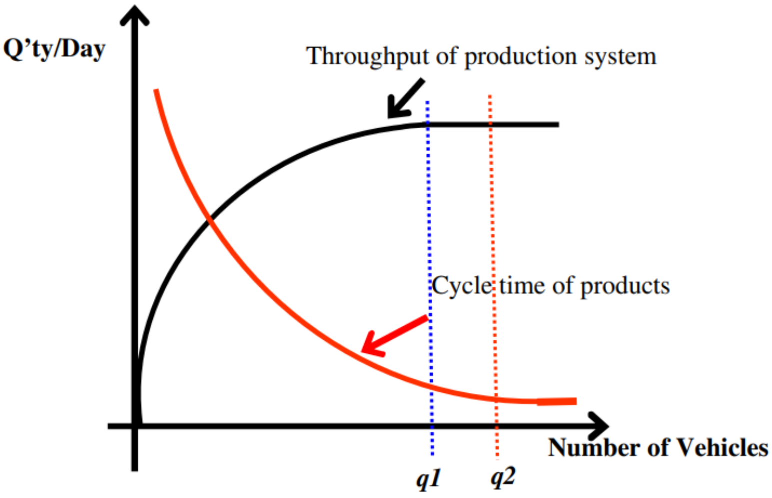


Figure 8: Relationship of throughput and cycle time vs. number of vehicles (Tu, Lu and Lee, 2013)

According to Vivaldini et al. (2016), the minimum number of AGVs can be determined by analytic, stochastic, and deterministic models. Deterministic models, such as the network flow model and linear programming models, can be used at the start of a real operation to estimate the number of vehicles required. Stochastic models, as queuing network, aim at incorporating external influences and can be used to determine vehicles requirements. The analytic model determines the number of vehicles considering the total travel time. Most analytic models reported in the literature have underestimated the number of vehicles required in comparison to the simulation approach. Many factors affect the number of vehicles required for handling the throughput in a system. Important vehicle characteristics, such as the guidance type, speed, capacity, and battery life, must be taken into consideration in the dimensioning of the optimal fleet.

A basic distinction can be made between single robots and multiple robots. Liu et al., (2016), argued how, when compared with single robot systems, a multirobot group has several substantial advantages, for example, the robot group can be built upon a group of low-cost robots, the robot group is robust against system failures caused by robot individual breaking down, and the robot group also facilitates distributed task implementation. For single robot, the transportation plan is more constrained by the robot capacity and the task time window constraints. This makes the transportation planning problem for single robot different and more complex than the traditional and known traveling salesman problem, which is a typical NP-hard problem in operational research.

4.2.4. PROBLEM FACED

The AMHS controller makes several decisions on the use and control of the vehicles. These include: dispatching decisions to decide which of the several AGVs to be used to transport materials/components; sequencing decisions to decide the order of use of AGVs, if several AGVs are used; routing decisions to decide the route to be taken to reach the machines; scheduling decisions to decide the start, wait and finish times to avoid collision and shop locking (deadlock or stalemate); loading decisions to decide on how much material per trip is to be carried for each of the machines (Veeravalli, Rajesh, Viswanadhams, 2002).

From this point of view, the totality of the articles read can be classified thanks to the definition provied by Fazlollahtabar, Saidi-Mehrabada and Balakrishnan (2015): "The vehicle management problems are classified into:

(1) dispatching, which is to assign tasks to vehicles;

(2) routing, which is to select specific paths taken by vehicles;

(3) scheduling, which is to determine the arrival and departure times".

All these decisions can be made simultaneously or separately. Most of the literature treats one or two of the problems at the same time. The same article explains that a widely used technique for dispatching is simulation. For routing and scheduling of AGVs, several techniques have been used to maximize the total system performance taking into account deadlocks or conflicts for AGVs. The simultaneous production scheduling and transportation routing problem is a difficult joint problem, given the huge number of variables. Several authors have tried to address the conflict free routing problem with a static transportation requests set, i.e., with all requests known a priori.

In the literature it is not common to find the subtle distinction between the concepts of dispatching and scheduling as defined above (see, e.g., Le-Anh, de Koster and Yu (2010)).

On the other hand, the substantial difference of the routing compared to the other two concepts is more marked, except for the use of the expression "vehicle routing problem" if defined as for example by Naso and Turchiano (2005) as: "the assignment of transport operations to vehicles".

In accordance with the definition of dispatching written above, Yim and Linnt (1993) deepen the concept in their article. In function of the relationship between the vehicle resource and the set of parts to be moved, dispatching rules are classified into "vehicle-initiated rules" and "workcentre-initiated rules".

When the number of unassigned loading tasks exceeds that of the free AGVs (in other words, the number of tasks exceeds the number of vehicles, so there are no idle vehicles), vehicle-initiated rules to prioritize the tasks are needed. The vehicle-initiated rules can be further classified into "source-drive rules" and "demand-driven rules". The source driven rule operates on a push concept: an idle vehicle selects a part to move from an output queue that has the highest priority, then a destination for the part will be determined according to the process selection rule specified. The demand-driven rule operates on a pull concept: an idle vehicle selects the part that has the highest demand from its succeeding workstations, then a list of parts that can be moved to this selected workstation is identified from the output buffers of other workstations. In other words, in the push-dispatching rule, the parts in the outgoing buffers of the workcentres are a major concern, while the incoming buffer status of each workcentre is a major decision factor in the pull-dispatching rule.

These are rules used in vehicle-initiated cases to select the part to be picked:

- Longest waiting time rule (LWT): select a part with the longest waiting time.
- Minimum remaining outgoing queue space rule with longest waiting part (MROQ): select a longest waiting part that is in the output buffer with minimum remaining queue space.
- First encounter first served rule (FEFS, also called Nearest vehicle rule NV): this third rule is explained by Lin, Wang & Yen (2001) and aims at minimizing the travel time of empty vehicle.

In case more workcentres need the same part, also a process selection rule needs to be defined. Two possible alternatives are:

- Longest inter-arrival time rule (LIAT): select a workcentre that has experienced the longest inter-arrival time of parts since the last job arrival.
- Maximum remaining incoming queue space rule (MRIQ): select a workcentre with maximum remaining queue space at the input buffer.

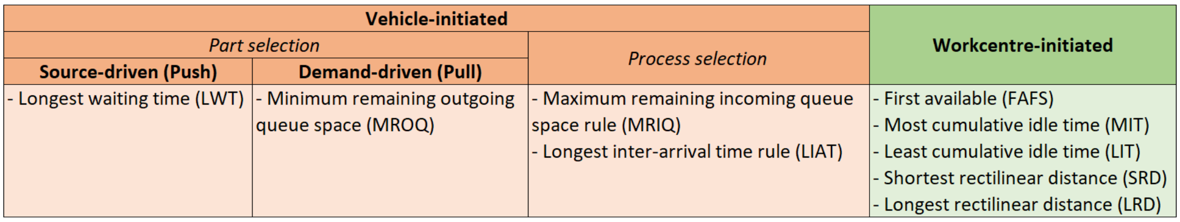
In workcentre-initiated rules instead, a workcentre has a part to be routed for the next operation and it selects a vehicle among a set of idle vehicles (in this case the number of idle vehicles exceeds the number of tasks). Cheng (1987) described five possible dispatching rules that fall in this category:

- FAFS: Select the first available AGV.
- MIT: select the AGV with the most cumulative idle time.
- LIT: select the AGV with the least cumulative idle time.
- SRD: select the AGV with the shortest rectilinear distance
- LRD: select the AGV with the longest rectilinear distance.

In the article it was found that the SRD and FAFS rules have the best performance, while the LRD rule performs moderately and the MIT and LIT rules are least effective.

Table 4 summarizes what has been explained above.

Table 4: Dispatching rules classification



Vehicle-initiated			**Workcentre-initiated**
Part selection		*Process selection*	
Source-driven (Push)	**Demand-driven (Pull)**		
- Longest waiting time (LWT)	- Minimum remaining outgoing queue space (MROQ)	- Maximum remaining incoming queue space rule (MRIQ) - Longest inter-arrival time rule (LIAT)	- First available (FAFS) - Most cumulative idle time (MIT) - Least cumulative idle time (LIT) - Shortest rectilinear distance (SRD) - Longest rectilinear distance (LRD)

4.2.5. HEURISTIC/EXACT

Among others, Boden, Rank and Schmidt (2020) pointed out that, in order to calculate solutions, either exact or heuristic algorithms, can be employed. Exact algorithms, like Branch and Bound, are applied to find solutions and prove them to be exact (e.g., the MIP model), but they are strongly restricted in problem size. Heuristic approaches (e.g., Neighborhood Search, Tabu Search, Simulated Annealing, Neural Network and Genetic Algorithm) are used to calculate solutions for more extensive problem instances than exact algorithms.

All the decisions related to MHS planning are a crucial part of real-time operations of production planners. It means that the best solution must be quickly obtained at the beginning of production shifts or during the shifts due to errors in a manufacturing cell (e.g., machine breakdown) or changes in a manufacturing cell's conditions (e.g., cycle time of production lines).

All authors in the literature agree that larger problems call for heuristic solutions. Nielsen et al., 2015, explain well the reason behind this need: as the problem is NP-hard, computation time exponentially grows with the size of the problem (e.g., longer planning horizon, larger number of feeders), hence mathematical methods, such as MIP, are only applicable to small-scale problems with few feeders and a short planning horizon. It is therefore necessary to develop a computationally effective algorithm, to solve the problem while satisfying a number of practical constraints. Usually, heuristics allow converting the problem of multiple-part feeding tasks of the mobile robot so that near-optimal solutions can be found in a period of time considered acceptable.

Some authors also make a further distinction between heuristics and metaheuristics. Although in this SLR this difference is not considered, as the goal is to distinguish between exact and approximate solutions, it is nevertheless useful to understand it. Heuristics are problem-dependent techniques, and they try to take full advantage of the peculiarities of the problem. Unfortunately, for this reason they could get trapped in a local optimum and thus fail, in general, to obtain the global optimum solution. Meta-heuristics approaches instead, are problem-independent techniques, which can be defined as "less greedy". In other words, they are willing to accept a temporary deterioration of the solution, which allows them to keep exploring the solution space and thus to get a hopefully better solution.

4.2.6. CENTRALIZED/DECENTRLIZED

Babiceanu, Chen and Sturges (2004) described the four basic types of control architectures (Figure 9), that are used to control either processing machines or material-handling systems:

- CENTRALIZED ARCHITECTURE (Figure 9a), a single control unit is in charge for all the decisions. This system has the advantage of having a simple architecture and the possibility of global optimization. However, it also presents some big drawbacks such as a slow speed of response when the system has a large number of resources, difficulty in making any changes, and the entire system does not work if the central control unit goes down.
- HIERARCHICAL ARCHITECTURE (Figure 9b), based on a top-down approach. Similarly, to the previous solution, a global optimization can be achieved, but it is still hard to work in case of changes or breakdowns. When the initial conditions for which the system was built are no longer valid, as in the case of disturbances such as machine breakdowns, the performance of the system deteriorates drastically. Because of the master–slave relationship between control units at adjacent hierarchy levels, the architecture is easy to understand, and the response time is shorter than in the case of centralized architecture.
- HYBRID ARCHITECTURE (Figure 9c), similar to hierarchical approach and it also allows cooperation and sharing of information between lower-level controllers. The supervisor initiates all the activities and then the subordinates cooperate to perform them. If there are changes made to the initial conditions, the supervisor takes the control, so that the lower-level controller decision is limited only to normal operation conditions. Since the involvement of the lower-level controllers in decision-making is limited, the hybrid architecture presents both the advantages and disadvantages of the hierarchical architecture.
- HETERARCHICAL ARCHITECTURE (Figure 9d), it is a pure decentralized approach, made by a group of completely independent entities. They bid for orders based on their status and future workload. There is no master–slave relationship like in the architectures presented above. All the agents including the manager of a particular order are bidding for it. Once the winning agent finishes the task, it automatically becomes the new manager for the incoming task. Contrary to the previous solutions, the system can react promptly to any change made to the system. On the other hand, it is impossible to seek global control optimization and the performance of the system is thereby unpredictable.

Almost all of the existing solutions can be classified according to this framework just described. Nevertheless, the simple distinction between centralized and decentralized is often found in the literature.

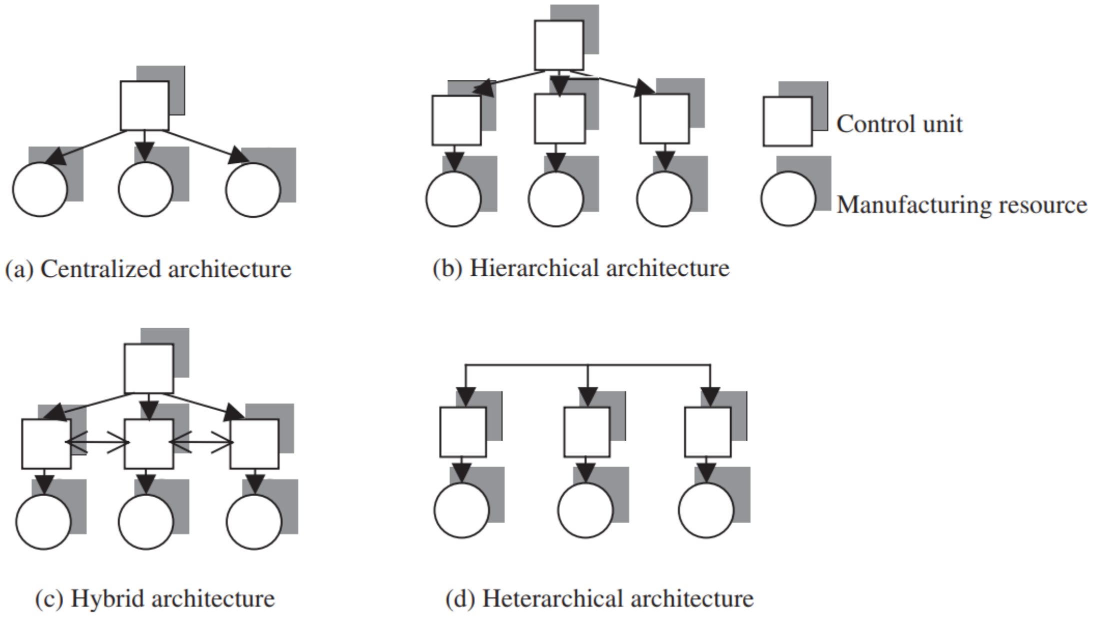


Figure 9: Traditional control architectures (Babiceanu, Chen and Sturges, 2004)

Cecchi et al., 2021, offer an interesting overview of the two approaches (centralized and decentralized), also arguing that one of the main challenges in current intralogistics is to reliably, effectively coordinate large-scale, heterogeneous multi-robot fleets without posing constraints on the infrastructure or unrealistic assumptions on robots. This coordination problem has been tackled by the scientific community with both centralized and distributed approaches.

In centralized approaches, there is one single decision-making entity that collects global information on the fleet (e.g., tasks, positions, and paths of all robots) and updates all robot actions accordingly. A global overview on the fleet as a whole allows performance optimization, nevertheless it may require a time that grows exponentially as computations increases. Therefore, to scale at large fleets, these methods often pose constraints on the infrastructure, robot kinodynamics, geometries, controllers, or all of the above. Based on Cecchi et al., 2021, a centralized approach can be scaled to tens of robots without imposing these unrealistic assumptions. However, communication uncertainty and/or real-time constraints may limit the ability of maintaining up-to-date snapshots of the fleet status. In the article it is suggested, among several options (such as improving wireless technologies, developing coordination algorithms with relaxed temporal requirements, etc.), to decentralize coordination to let robots autonomously decide their future actions based on local information and communication with nearby robots, as they state that: “thanks to locality, in fact, decentralized approaches are less prone to communication uncertainty. These methods can be made robust to lack of global information and central unit faults, and scale more easily to large fleets”. On the other hand, this kind of method is less able to enforce liveness or optimality.

Fregapane et al., 2021, talking about the difference between AGVs and AMRs, provided a graphical representation of the difference between centralized and decentralized approach (showed in Figure 10): compared to an AGV system in which a central unit takes control over decisions such as routing and dispatching, AMRs can communicate and negotiate independently with other resources like machines and systems and take decision themselves (in this case AGVs move on defined paths, even if this constraint is not always true).

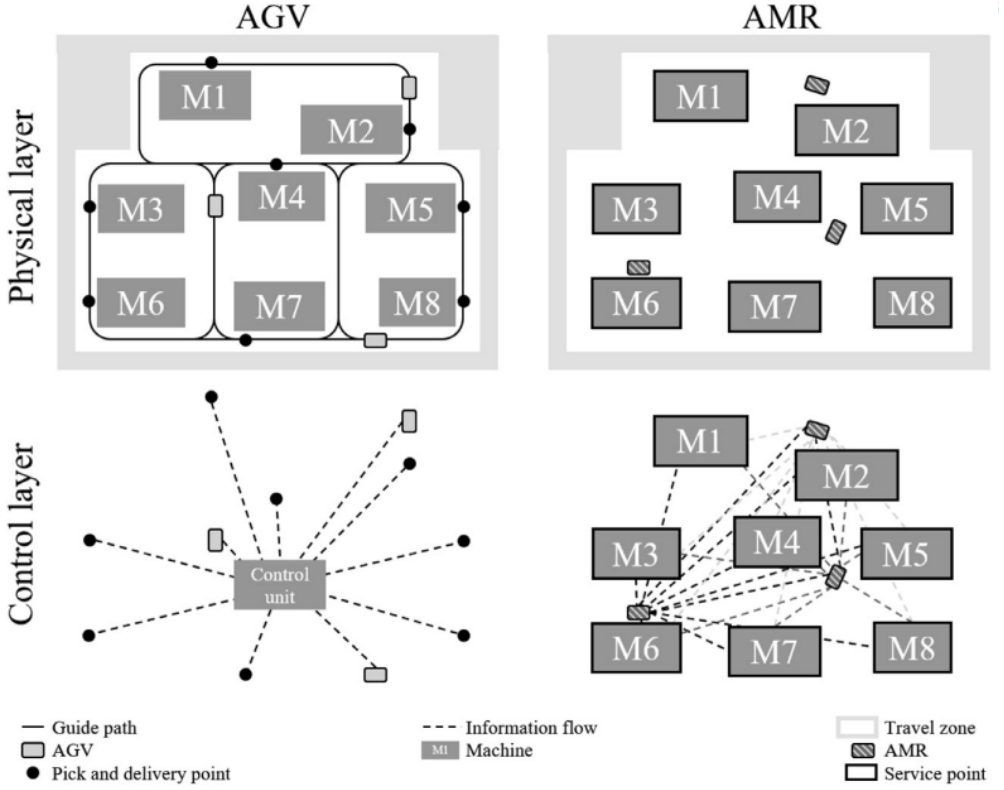


Figure 10: Centralized AGV control and decentralized AMR control (Fregapane et al., 2021)

4.2.7. SCOPE

The scope of the scheduling refers to the possibility of scheduling either the MHS or the MHS and the production lines. Simultaneous scheduling consists in simultaneously considering machine scheduling and the scheduling of the MHS, in order to exploit the interactions between them. As opposed to an independent scheduling, in this way the MHS scheduling actively participates in the scheduling of machines, instead of just reacting to it.

Simultaneous scheduling allows higher throughput and lower makespan, but it brings with it more difficulties. “Simultaneous real-time scheduling issues in FMS are dynamic, complex and typical in nature. The simultaneous scheduling issues may prompt out due to change in production quantity, quality, change in delivery dates and also due to the variation in processing requirements. […] To achieve low makespan and high throughput yield in the FMS operations, it is highly imperative to integrate the production work centers schedules with the AGVs schedules.” (Chawla, Chanda and Angra, 2019).

4.2.8. STATIC/DYNAMIC

As Hu et al. (2020) explained, traditional static scheduling approach usually assumes that all the task information is stable and obtained in advance, and then establish an analytical model and solve it. However, it is unrealistic to be informed all the task information beforehand in a real-world shop floor. Furthermore, many uncertainties (such as urgent task, task reworks, etc.) also exist on such a dynamic and complex shop floor environment. Therefore, the static scheduling approach is insufficient for the complicated real-world shop floor.

Yao et al., 2020, provided a classification of FMS scheduling methods perfectly overlapping with the distinction between “static” and “dynamic” made in this SLR. According to their article: “offline methods” are used to schedule FMS operations based on the entire production planning, in which all product components are assumed to be available prior to the start of the production; “online (real-time-based) methods”, in contrast, aim at scheduling manufacturing operations at the execution phases in which shop-floor scheduling decisions are required as the manufacturing system’s status changes. The second class of methods allows companies to dynamically schedule their production systems to match the desired customer demands promptly.

4.3. DISCUSSION

4.3.1. DIMENSIONS

While in the previous paragraphs the typical context in which the MHS operates has been described, and the main variables that characterize and allow to distinguish different solutions have been identified and shown, in this last point of the section there is a more quantitative and practical overview of the literature.

Below, Table 5 classifies the articles read, taking into account the relevant dimensions described above.

Table 5: Classification of articles according to the identified dimensions

		CONTROL FRAMEWORK		SCOPE		UPDATING		SOLUTION		PROBLEM FACED		
Authors	**Year**	**CENTRALIZED**	**DECENTRALIZED**	**MHS**	**MHS + PRODUCTION SYSTEM**	**STATIC**	**DYNAMIC**	**EXACT**	**HEURISTIC**	**ROUTING**	**DISPATCHING**	**SCHEDULING**
Fregapane et al.	2021		X	X			X			X	X	X
Bányai, T.	2021	X			X		X		X	X	X	X
Cecchi et al.	2021		X	X			X		X	X		
Zhou, Fei	2021	X		X		X			X		X	X
Zhou, Li, Zhang	2021	X		X		X			X			X
Boden, Rank, Schmidt	2021	X		X		X		X				
Lee et al.	2021	X		X			X		X	X		
Yao et al.	2020				X		X		X		X	X
Hu et al.	2020	X			X		X				X	
Rahman, Janardhanan, Nielsen	2020	X			X		X		X		X	X
Boden, Rank, Schmidt	2020	X		X			X		X		X	X
Wojcik et al.	2020	X		X		X			X		X	X
Németh et al.	2019	X			X					X		
Rivas, Ribas-Xirgo	2019		X	X			X	X				X
Karamanos et al.	2019	X		X			X		X	X		
Chawla, Chanda, Angra	2019	X			X	X			X		X	X
Bányai, Á. et al.	2019	X		X			X		X	X	X	X
Kousi et al.	2019	X		X			X	X		X	X	X
Emde, Abedinnia, Glock	2018	X		X		X			X		X	X
Zhou, Xu	2018	X		X		X			X	X	X	X
Emde, Gendreau	2017	X		X		X			X		X	X
Nielsen, Dung et al.	2017	X		X			X		X		X	X

Nielsen., Dang et al.	2017	X		X			X	X	X		X	X
Liu et al.	2016	X		X			X		X	X	X	X
Khosiawan, Nielsen	2016	X		X			X			X	X	X
Zabihzadeh, Rezaeian	2016	X			X	X			X		X	X
Vivaldini et al.	2016	X		X			X		X	X	X	X
Caridá, Morandin, Tuma	2015	X				X					X	X
Fazlollahtabar, Saidi-Mehrabad, Balakrishnan	2015	X		X		X			X	X		X
Dang et al.	2014	X		X				X	X		X	
Tu, Lu, Lee	2013	X		X		X		X				
Zhou, Che, Yan	2012	X		X				X			X	X
Chen et al.	2011	X		X			X		X		X	X
Boysen, Bock	2011	X				X	X	X	X		X	X
Le-Anh, De Koster, Yu	2010	X		X		X	X		X		X	X
Naso, Turchiano	2005	X		X			X		X		X	
Babiceanu, Chen, Sturges	2004		X	X			X				X	X
Farahvash, Boucher	2004	X		X	X		X			X	X	X
Singh, Tiwari	2004			X			X				X	
Veeravalli, Rajesh, Viswanadham	2002	X			X	X		X		X	X	X
Choi, Lee	2002			X			X			X	X	X
Qiu, Hsu	2001	X		X		X		X		X		
Lin, Wang, Yen	2001	X		X		X			X		X	
Soylu, Özdemirel, Kayaligil	2000	X							X	X	X	
Kozan	2000			X		X		X	X	X	X	
Kats, Levner, Meyzin	1999							X			X	X
Ganesharajah, Hall, Sriskandarajah	1998											
Anwar, Nagi	1998	X			X	X			X		X	X
Thonemann, Brandeau	1997	X		X		X		X			X	X

Shah, Lin, Nagi	1997	X		X			X			X	X	
Thonemann, Brandeau	1996	X		X		X		X			X	
Arneson	1996											
Lee	1996	X		X		X			X		X	
Lee, DiCesare	1994	X			X	X			X	X	X	X
Interrante, Rochowiak	1994	X	X	X			X	X	X	X	X	
Yim, Linnt	1993	X		X		X			X		X	
Sepulveda, Sullivan	1988	X		X			X		X	X	X	X
Cheng	1987	X		X		X			X		X	
Egbelu, Tanchoco	1984	X		X		X			X		X	

Figure 11 shows the statistics concerning each dimension, in particular for each of them the percentage of articles that fall into each possible class of the dimension.

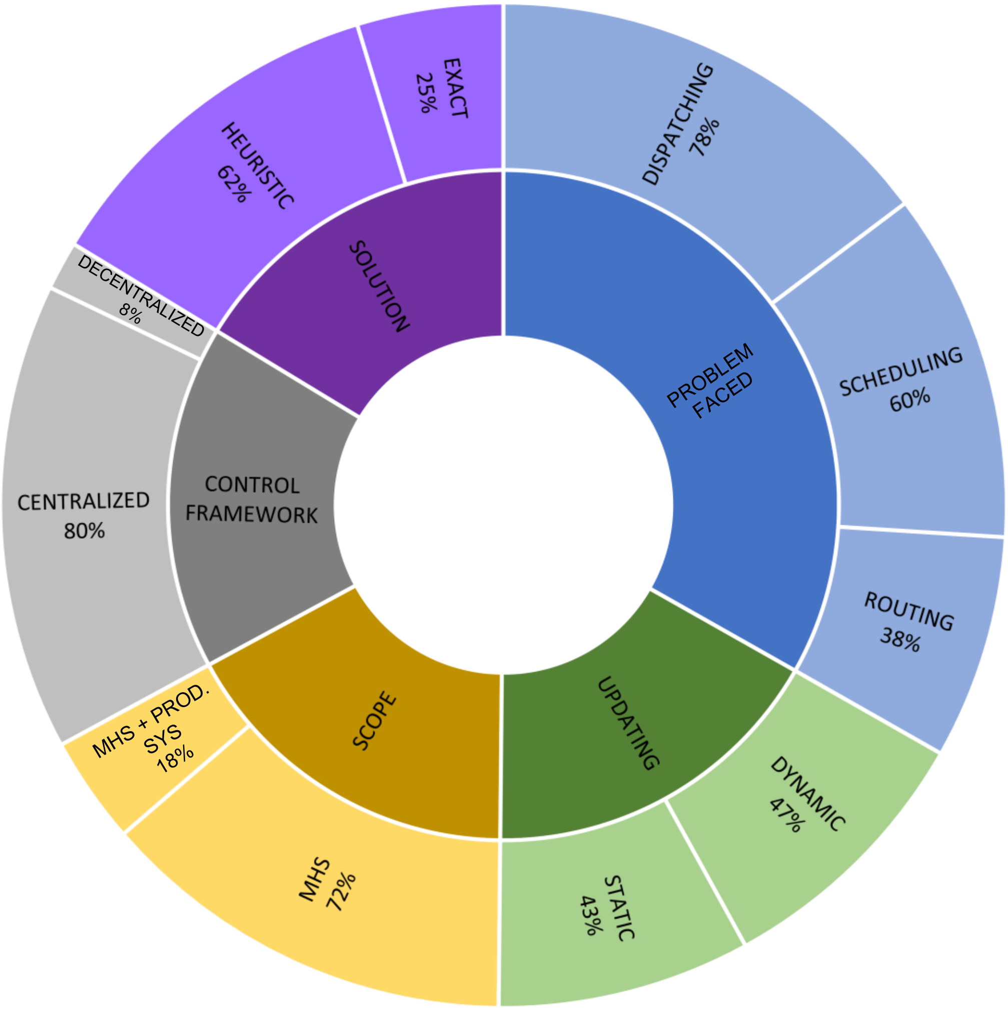


Figure 11: Dimensions statistics

Looking at the graph, the situation seems to be balanced for the dimension of updating.

Different discourse applies to the problem faced, as in this dimension an article can deal with several problems at the same time. It is therefore interesting to make evaluations taking into account, for each article, the three possible alternatives simultaneously. The routing problem was the least treated of the three. This data can be justified by clarifying that 22/59 articles present predefined and bound paths for robots, and of these only 5 articles deal with routing.

While there does not seem to be a correlation between its presence in the articles and that of scheduling and dispatching, the latter two are definitely linked (out of 47 articles that deal with dispatching, 44 also deal with scheduling).

The exact solutions are much less than the heuristic ones. Zhou and Fei, 2021, stated: "Due to the NP-hard nature of the problem, the solution found using exact algorithms is far away from the optimum within a limited time. Moreover, the search space will increase rapidly for solving the medium- and large-scale problem matching with the actual production environment, which further exposes the shortcomings of the exact algorithm. Therefore, more and more researchers have been putting more emphasis on looking for faster and better heuristic algorithms to solve the NP-hard problem". This explanation perfectly reflects the high percentage of heuristics solutions.

Yao et al., 2020, in their classification of FMS scheduling methods in offline e online (real-time based), also clarified that the applied methods on the offline scheduling can be further divided into the following categories: (i) the exact methods, (ii) heuristics, and (iii) simulation-based methods. While, online approaches are, in general, time-constraint methods in which a limited amount of computation time is provided to generate a set of optimal scheduling solutions. In this SLR the distinction between exact and heuristics solutions does not refer a priori to static approaches only (unlike Yao et al. 2020). Despite this, the two searches are not in contrast with each other, as it can be seen from Table 5 that almost all the dynamic approaches offer a heuristic solution.

Control framework dimension is very unbalanced, with very few decentralized solutions. This dimension seems to be affected by other two, since all decentralized approaches are purely dynamic and limited to MHS, neglecting other processes. This is not true for centralized approaches.

Regarding the scope dimension, there is a strong propensity to limit the scheduling to the MHS rather than extending it to other processes as well. This result is also confirmed by Rahman, Janardhanan and Nielsen (2020), that stated: "Simultaneous balancing a robotic assembly line and the scheduling of material handling has received limited attention in academia. In modern manufacturing industries, robotic assembly line balancing and AGV-based material delivery scheduling problems are interrelated, and they should be considered simultaneously. However, to the best of the authors' knowledge, researchers have studied these problems separately. Hence, there is a gap between the theoretical research on the assembly line balancing problem and real-world application".

Most works have addressed the problems as two independent entities, assuming sufficient capacity in the transport system to satisfy the production plans of other processes, and therefore not considering the link between the MHS and the production system

4.3.2. OBJECTIVES AND CONSTRAINTS

As regards the objectives pursued and the constraints considered, these two variables are descriptive rather than dimensional, therefore they deserve a separate discussion.

As can be seen from Figure 12, the most common goal is to minimize time.

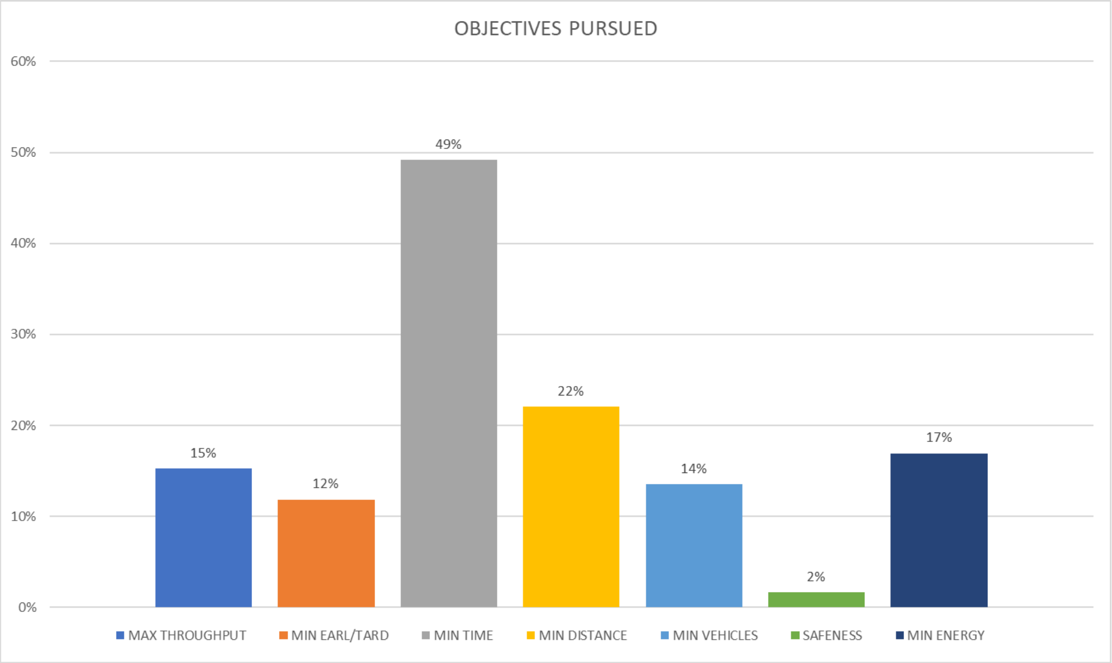


Figure 12: Objectives pursued statistics

Among other objectives, distance minimization and throughput maximization are also relevant. As is well known, among the activities of the MHS, pure transport is the one that takes up the most time. Furthermore, there is an inverse proportionality relationship between time and throughput. This shows that, even if classified as three different types of objectives, they are related to each other. Earliness/tardiness minimization allows to maximize the throughput of the whole production process and can be achieved with an effective scheduling and of course if the time required by the MHS is low, its achievement becomes easier.

The objective regarding the energy consumed reflects two interests: safeguarding the environment and saving costs. The first is a theme that has been emerging in recent years. The second is related to the minimization of distance, as the movement of vehicles is the most expensive activity in terms of energy.

In reality, the minimization of the energy consumption of the vehicle fleet also passes through the minimization of the number of vehicles in the system, which in turn allows to achieve objectives of minimizing investment costs and minimizing congestion problems. It is important to clarify that among all the solutions proposed, few of these also deal with the identification of the number of vehicles in the fleet. Not considering this variable, it follows that they do not have its minimization as their goal.

Lastly, with a very marginal weight, there is the objective linked to safeness, which is exclusively part of a routing problem.

Figure 13 graphically shows the links between the various objectives, explained above.

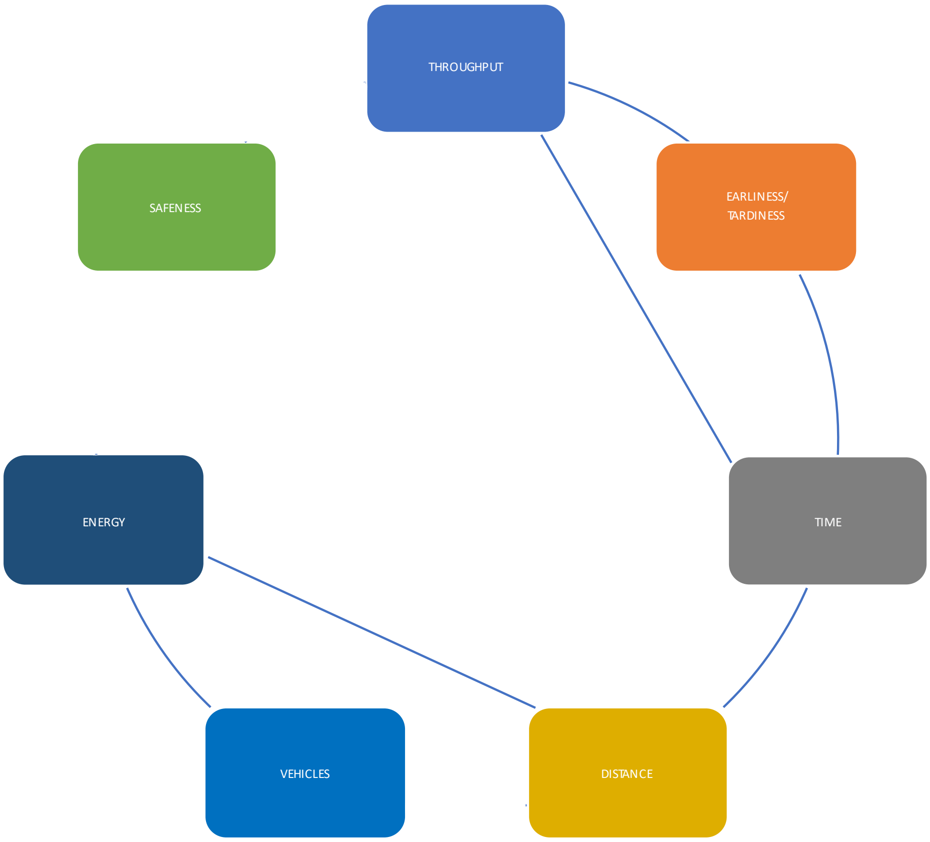


Figure 13: Relationships between objectives

Concerning the considered constraints (Figure 14), the most visible data is that only 17% of the publications considered "allows" the vehicle to visit more stations in a mission. Of the three categories of constraints considered, this is the only one that does not place a limit on the applicability of the solution in a real context. Nevertheless, the possibility to visit multiple stations in a mission has important consequences on the nature of an approach, its development, and its performance. The difference between solutions that allow or not this variable becomes more marked in those contexts where the fleet is made up of a single vehicle (6 out of 8). To the best of author's knowledge, none of the publications considered has focused on this aspect, which therefore needs to be deepened and studied.

As regards the feasibility of an approach, the solutions should be designed while taking into account a number of practical constraints. The two constraints identified are the time window and the capacity. They are definitely more considered with respect to the previous one, but looking at those articles that include them simultaneously the percentage goes down to just 32% (19 out of 59).

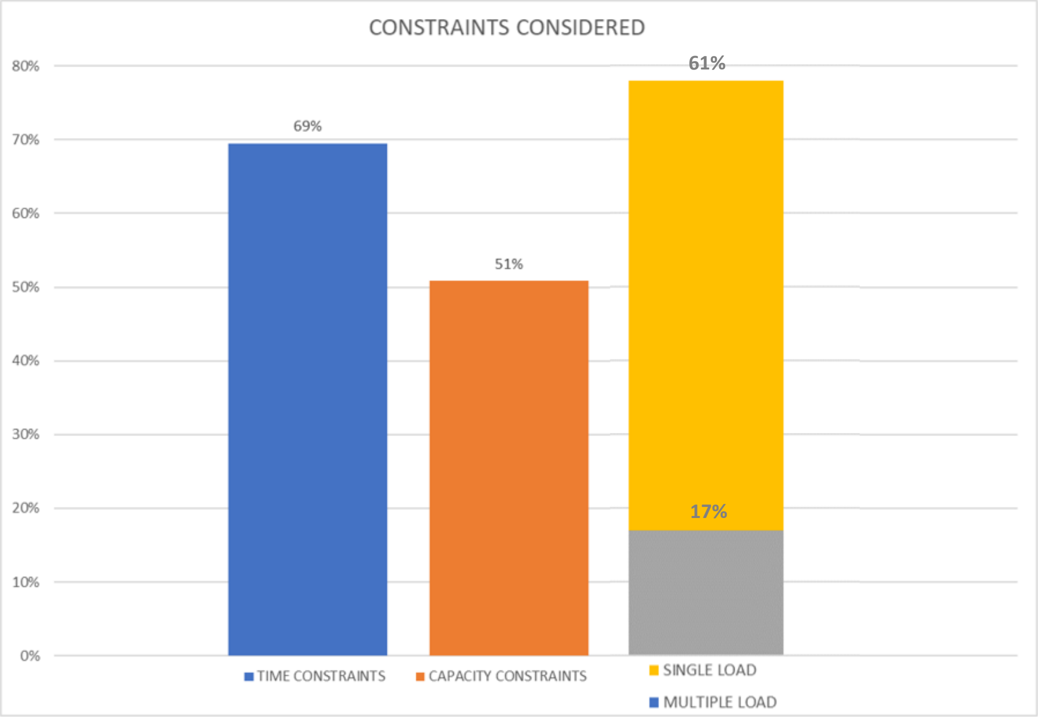


Figure 14: Constraints statistics

It is of fundamental importance to underline that all the considerations made above, regarding all the dimensions identified, completely ignore the temporal dimension of the publications and the advent of Logistics 4.0. This factor is described and considered in the next section.

5 RQ2: IMPACT OF LOGISTICS 4.0 ON TASK ASSIGNMENT

5.1. LOGISTICS 4.0

Among other factors, digitization and Industry 4.0 technologies are pushing today’s economy towards a significant transformation process regarding the fulfilment of customers’ demands. Production companies must apply the solutions of the fourth industrial revolution to improve their efficiency. Logistics and material handling operations have more and more importance related to the production, distribution, and reverse processes, and they have a significant impact on the strategic, tactical, and operative level of enterprise systems (Bányai, T., 2021).

Logistics 4.0 is essentially the application of fourth industrial revolution concepts to logistics operations, but while the opportunities stemming from Industry 4.0 have been widely explored in manufacturing processes, further research is needed to study their application in the logistics field in general (Modica et al., 2021). In particular, how the Industry 4.0 design principles can affect the design and the configuration of logistics processes is still to be clarified.

Bányai, T., 2021, explained how the Industry 4.0 technologies influence the production, in detail the matrix production.

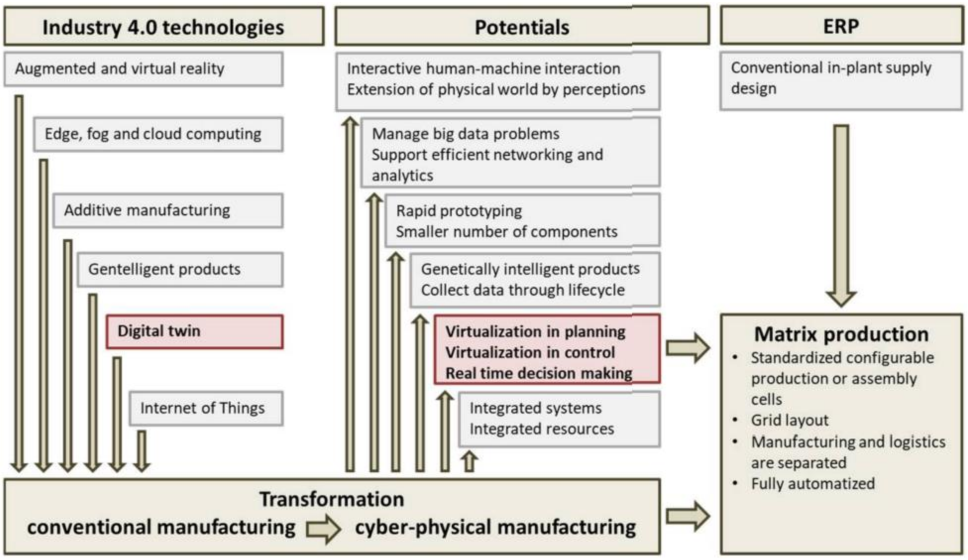


Figure 15: Industry 4.0 technologies' impact on matrix production (Bányai, T., 2021)

As Figure 15 shows, Industry 4.0 technologies offer new innovation accelerators, like augmented and virtual reality, cloud and fog computing related to big data problems, additive manufacturing, Internet of Thing (IoT), autonomous standardized production and material handling resources, smart tools, gentelligent products, simulation and digital twin solutions, cyber security, and system integration. Augmented and virtual reality is a key technology for smart manufacturing because it makes it possible to realize an interactive human–machine interaction in a real-world environment while the components of the physical world are extended by perceptual information. Complex manufacturing systems generate unprecedented amounts of data that are difficult to handle with traditional computing methods. Cloud, edge, and fog computing make it possible to manage big data problems. The new concept of gentelligent products aims to develop genetically intelligent products and components, which collect data through their lifecycle and bequeath them to the next generation in various time spans. The application of digitalization-based technologies enables the virtualization of product and process planning and control. Digital twins represent an integrated probabilistic simulation of complex products or processes using physical models, sensor updates, and cloud-based information to mirror the product or process of its corresponding twin. Digital twin technology makes it possible to convert conventional manufacturing systems into cyber-physical systems, and this transformation can lead to the improvement of the design process of in-plant material supply, adding a real-time phase to the conventional in-plant supply process. In conventional manufacturing systems, the real time optimization is almost impossible, because real time optimization is based on real time data and status information. Using digital twin technology and smart sensor networks, real time data and status information can be collected from the physical system, and a real time model for discrete event simulation can be generated to perform scenario analysis for real time decision making. The IoT describes an integrated system of computers and mechanical machines provided with unique identifiers. The IoT in manufacturing systems makes it possible to transfer data through a network among manufacturing equipment (standardized production cells and assembly cells), materials handling machines (autonomous mobile robots and automated guided vehicles), intelligent tools, gentelligent products, and Enterprise Resource Planning (ERP) systems. The Industry 4.0 technologies make it possible to transform conventional manufacturing processes to cyber-physical manufacturing processes to aim for higher flexibility, productivity, availability, cost-efficiency, energy-efficiency, and sustainability.

Fourth Industrial Revolution brings opportunities, which however make the system more complex and therefore new design and operation problems arise.

Fregapane et al., 2021, have provided a literature review that highlights how autonomous mobile robots (AMR) technological advances affect planning and control decisions. According to the authors: “compared to an automated guided vehicle (AGV) system in which a central unit takes control of scheduling, routing, and dispatching decisions for all AGVs, AMRs can communicate and negotiate independently with other resources like machines and systems and thus decentralize the decision-making process. Decentralized decision-making allows the system to react dynamically to changes in the system state and environment. These developments have influenced the traditional methods and decision-making processes for planning and control”. Some of the main features of the AMRs are:

i. possibility to have full recognition of the environment and mapping process thanks to sensors;
ii. increased flexibility in the movement and positioning thanks to locomotion mechanism;
iii. manipulating equipment that allows new possible operations;
iv. ultra-low-power AI processors that allow real-time decision-making in both navigation and providing services.

The new developments and possibilities of AMRs incorporate many of the typical innovations of Industry 4.0. Therefore, the new decision-making framework for planning and control can make an important contribution to Logistics 4.0 for material handling in general, not just a fleet of AMRs.

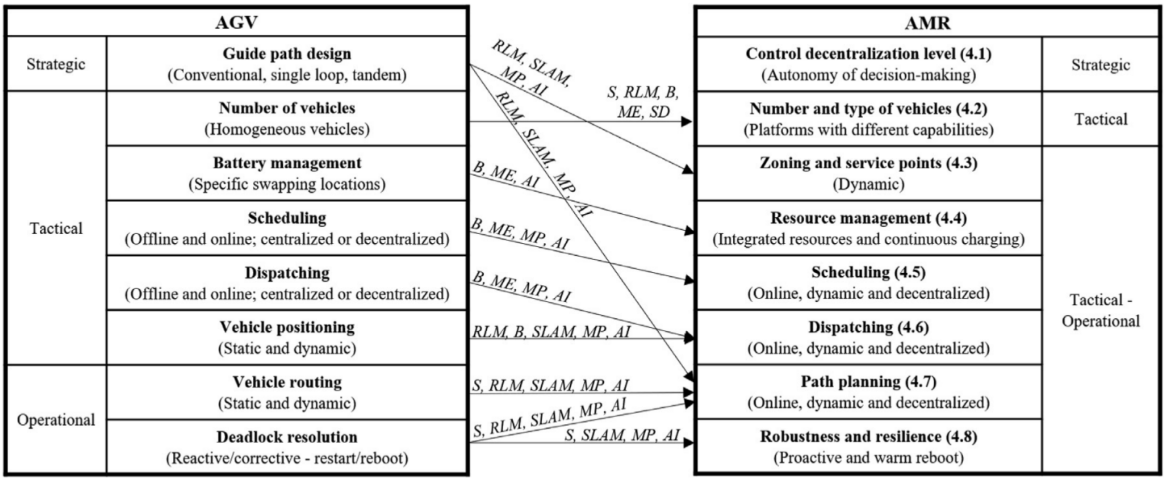


Figure 16: Impact of technological developments on planning and control decision areas for AMRs (Fregapane et al., 2021)

Changes in the planning and control environment from hardware and software developments have changed the traditional decision areas to the following ones for AMRs, and again in general to the new environment enabled by Logistics 4.0 (Figure 16): (i) the control decentralization level, (ii) the number and type of vehicles, (iii) zoning and service points, (iv) resource management, (v) scheduling, (vi) dispatching, (vii) path planning and (viii) robustness and resilience. Points (ii), (iii) and (iv) are not necessarily related to Industry 4.0 technologies' novelties, therefore they will not be further investigated.

A different perspective is suggested by Modica et al., 2021: due to the multitude of technologies related to Industry 4.0 and the continuous evolution of the context, an approach that focuses more on the design principles, rather than the single technology, may better describe the transition towards Logistics 4.0.
A model that considers the evolutionary nature of the phenomenon is the so-called "maturity model", which makes it possible to measure organizational readiness and develop action plans for implementing Industry 4.0 technologies. Despite this, so far there are few studies that have addressed the development of maturity models, and those that have did that, have mostly a perspective on the entire supply chain and not on logistical processes.

The framework proposed by Modica et al., 2021, is shown in Figure 17 and is explained as follows.

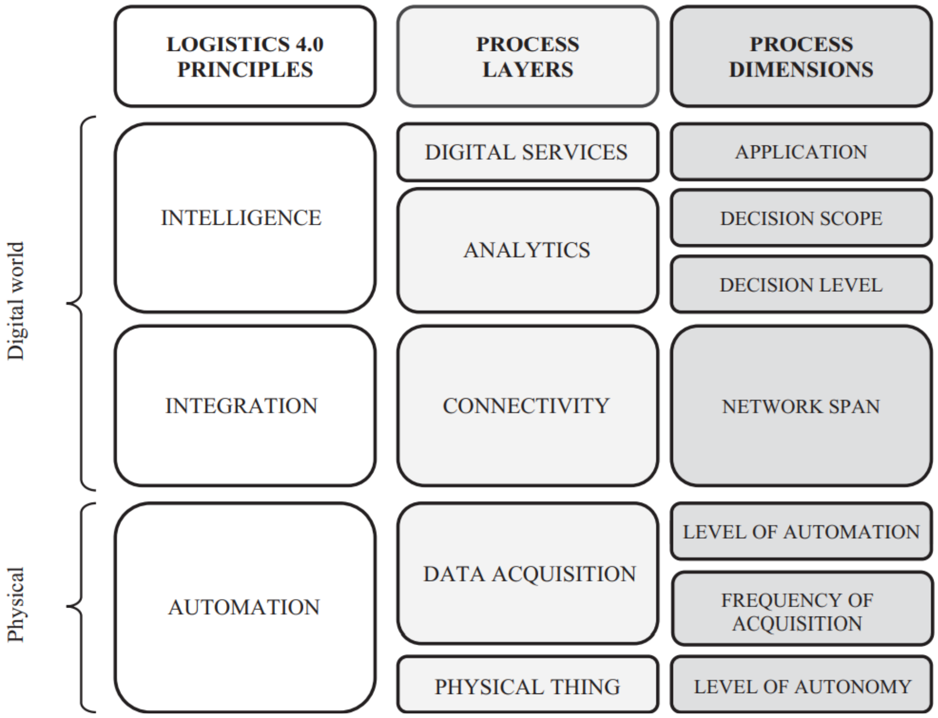


Figure 17: Conceptual framework for Logistics 4.0 in transportation (Modica et al., 2021)

Actually, the framework is for Logistics 4.0 in transportation. The nature of this process is different from that of material handling but, analysing the model and considering other articles, it can be seen that it can be adapted to both processes.

In detail, the framework is developed on three principles:

- AUTOMATION
  It can create value in transportation processes as well as in part feeding. According to Nielsen et al. (2015), utilization of the mobile robot instead of humans can reduce the dependence on human intervention, making multiple part feeding tasks more flexible and efficient. Automation takes place through two process layers, Physical Thing and Data acquisition. Material handling process should be designed so that Physical Things (mobile robots or means of transport in general) carry out physical tasks and collect and exchange real-time data autonomously (with a given level of automation and a given frequency of acquisition).
- INTEGRATION
  Data acquisition is the starting point of the virtualization of the physical world. It is crucial that the collected data are accessible to all the actors involved in the process (machines, operators, mobile robots, etc.), so that communication among them is possible. That is why the Integration principle is translated into the Connectivity process layer. The related process dimension is the Network Span, which refers to the number of players able to access the information. In case of intralogistics, those players are machines, operators, mobile robots but also other actors of the working inside and outside the plant.
  The integration process makes it possible to consider both the production and the transportation activities during the scheduling for instance.
- INTELLIGENCE
  Artificial Intelligence (AI) software is capable of learning from experience, differentiating it from more conventional software which is pre-programmed and deterministic in nature. AI does not necessarily mean giving intelligence or consciousness to machines in the same way that a person is intelligent and conscious. It simply means the machine is able to solve a particular problem or class of problems.
  The intelligence principle of Logistics 4.0 gives the opportunity to perform decentralised decisions, interpreting local and global data. Intelligence is embedded in the two process layers, Analytics and Digital Services.

5.2. RESULTS

5.2.1. CONTROL DECENTRALIZATION LEVEL

The level of decentralization is a fundamental strategic decision. Determining which parts of a system should be controlled in a centralized or decentralized manner plays a crucial role in defining the interfaces between AMRs and their operating environment.

A few studies have investigated the decentralization of control areas beyond path planning. Among them, Rivas and Xirgo (2019) proposed an agent-based approach, stating that as vehicles increase the degree of autonomy, transport systems inside those facilities look more like transport systems in urban areas. The authors described a decentralized task allocation in which AMRs can negotiate with or bid against other machines for task assignments. The idea at the basis of this solution is the following: the typical context of internal transportation in industrial and logistics plants, can be considered as a city in which taxis (mobile robots) carry clients (transport orders) from one point to another. In this model, closed envelope auctions determine which taxis carry which passengers. The latter take the lowest bids from the former. Also, re-auctions are allowed while a taxi is already on its way to pick it up, and it is possible to reassign the order to a different taxi in case it wins the re-auction. Taxis are the agents that perform the TOs; when available, they send their transport proposal, along with its cost, to any passenger asking for transportation, and begin to perform it once they receive the approval from the passenger. When a taxi proposal is accepted it begins to travel the route to the passenger but keeps listening to any incoming message in case the passenger makes a re-auction or another taxi wins the TO, so it must abort the travel.

Taking decisions autonomously thanks to AI promotes the decentralization of activities.

As already introduced by Babiceanu, Chen and Sturges (2004), a decentralized control framework is part of the existing traditional solutions, since before the advent of Logistics 4.0.

It can therefore be said that Logistics 4.0 is not a necessary means for the decentralization of activities, rather it helps their implementation and improves their effectiveness. Novelties like AI, digital twin, etc. allow the realization of a solution that is ideally not new at all.

This solution was clearly described by Babiceanu, Chen and Sturges (2004), which they named "Holonic control architecture", as follows: "Having more than one control unit, this architecture is different from the traditional centralized control architectures used for small manufacturing systems or cells having only one control unit for the whole manufacturing system. It can be seen that the flow of information between control units is always bi-directional due to the decentralized nature of the architecture and the application of the holonic concept of cooperation. The holonic architecture is formed by five types of entities: Order Holons (OHs), three types of Resource Holons (RHs) (Machine, Material Handling, Equipment), and another entity called a Global Scheduler (GS) that holds a general image of the entire system. […] an OH represents a job and all its associated information embedded in one control unit, while the RHs are represented by the physical manufacturing resources, each having its own control unit. […] To monitor the number of jobs and the availability of resources in the system, and to keep track of the already executed jobs, another entity called System Monitoring and Database (SM&DB) is introduced". Applying this concept to MHS, some changes must be made: the only RHs are numerous Material Handling Holons, and there are many OHs. The result is showed in Figure 18.

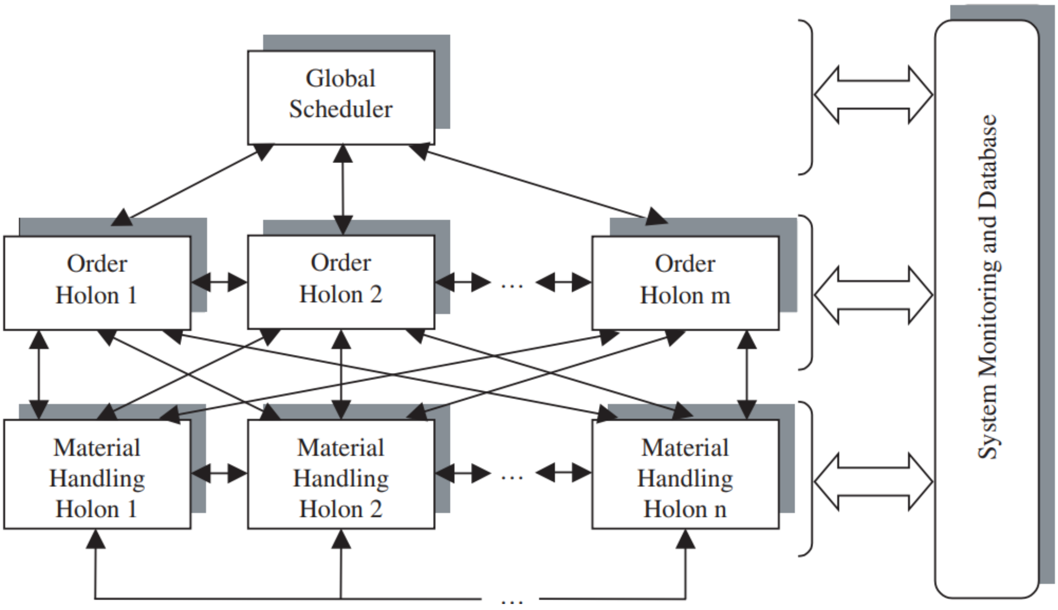


Figure 18: Material-handling holonic control architecture (Babiceanu, Chen and Sturges 2004)

The strong decentralized nature can be observed by analysing in detail the relationships between the various units of the architecture. GS is basically a control unit that can deliver optimal schedules for the material-handling equipment, like a central control unit. The difference is that those schedules are treated as recommendations by the decision-making entities, not as mandatory orders.

Moreover, the GS proposes its solution when the system is operating under normal conditions, otherwise the MHHs are free to change existing schedules due to unexpected events. The OHs, created whenever a new job enters the system, are the entities with the authority to award transportation tasks to the MHHs. By comparing the transport offers received from the MHHs and the schedule received from the GS, the OHs assign the transport operations to the individual MHHs. From this point of view, the OHs can be viewed as the system decision-making units. Thanks to these properties, the holonic system can work both as a hierarchical system, during normal operation when no disturbances are present, and as a heterarchical system, when facing sudden disturbances.

This concept seems very similar to the solution of Rivas and Xirgo (2019) described above.

The next question to be answered, without reaching conclusions given by intuition alone is: is a decentralized system really worthwhile compared to a centralized one?

According to Fregapane et al., 2021, decentralized control can often access only local information and find local optimal solutions for systems with multiple objectives, which are globally suboptimal. Nevertheless, with a greater variety of operations and a more unstructured environment, decentralized control can achieve high performance. Large-scale, complex systems often require decentralized systems, given the large number of decision states to be considered and the computation time required with a centralized approach. In case of decentralized approach, the decision making is distributed among multiple units, taking only local factors into consideration, and requiring less time. This also allows further reduction of the recovery time after failure. Centralized control on the other hand requires a long time to evaluate the state of every single mobile robot after failure and to coordinate the entire fleet to recovery. Figure 19 graphically shows what has been said above.

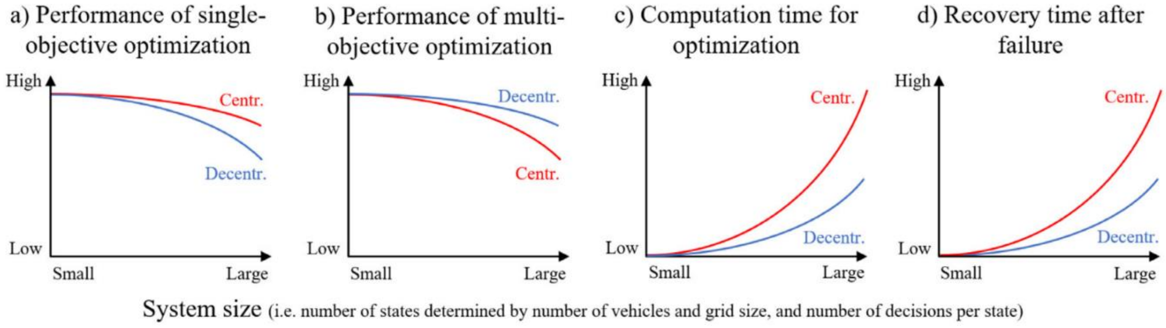


Figure 19: Centralized vs. decentralized control in small and large systems (Fregapane et al., 2021)

Therefore, it is crucial, at the strategic decision level, to provide methods to determine the most suitable control decentralization level for the different decisions area such as scheduling, zoning, or path planning.

In the same article it is mentioned that, although decentralized decision-making has received increasing research interest, few studies have investigated the conditions under which decentralized control is more profitable compared to centralized control, or results in higher performance.

Among all the articles considered by Fregapane et al., 2021, it emerges that system throughput and throughput time are the decisive performance measures when analysing and deciding on the control decentralization level, and that simulation modelling has been the main method. Moreover, most studies have been conducted in manufacturing rather than in other intralogistics areas (7/11 papers), which might be traced back to the strong promotion of Industry 4.0 to decentralize material handling.

5.2.2. SCHEDULING

Driven by the recent advances in IoT and industrial AI, lots of information technology (RFID, embedded device, augmented reality, etc.) and industrial robot (Robotic arm, mobile robot, etc.) have been widely adopted in production shop floor.

Manufacturing industries focus on full autonomy because of the rapid advancements in different elements of Logistics 4.0 such as the IoT, big data and cloud computing. In smart assembly systems, this autonomy aims at the integration of automated material handling equipment such as AGVs to robotic assembly line systems to ensure a reliable and flexible production system (Rahman, Janardhanan, Nielsen, 2020).

Hu et al., 2020, explains the difference between traditional scheduling, and the new possibilities enabled by Logistics 4.0. Traditional static scheduling approach usually assumes that all the task information is stable and obtained in advance, and then establish an analytical model and solve it with the heuristic algorithm. This approach is insufficient, because of the unrealistic assumption that does not consider the unpredictability of the information and many uncertainties, such as urgent tasks, reworks, etc.

In recent years, with the help of IoT technology, many scholars focused on the real-time scheduling in AGVs and production system to address the dynamics in shop floor operation environment. Logistics 4.0 technologies allow the creation of a cloud-based cyber-physical system that enables adaptive shop-floor scheduling and condition-based maintenance.

Hu et al., 2020, proposed a Deep Reinforcement Learning (DRL) method for flexible shop floor to minimize the makespan and delay ratio. Figure 20 shows the architecture of the approach. On the bottom, the shop floor is clearly integrated with Industry 4.0 technologies, hence is able to exchange real-time environment information such as status of production, tasks, etc. The Deep Q-Network layer (DQN), composed by three modules, extracts key data, process them, and continuously learns, and finally interprets results by selecting the appropriate rule and sending it back to the shop floor.

Comparisons made by authors show that better performance can only be achieved by choosing the most appropriate rule according to different situations. Therefore, the experimental results can prove the effectiveness and reliability of the proposed approach for AGVs real-time scheduling in the flexible shop floor.

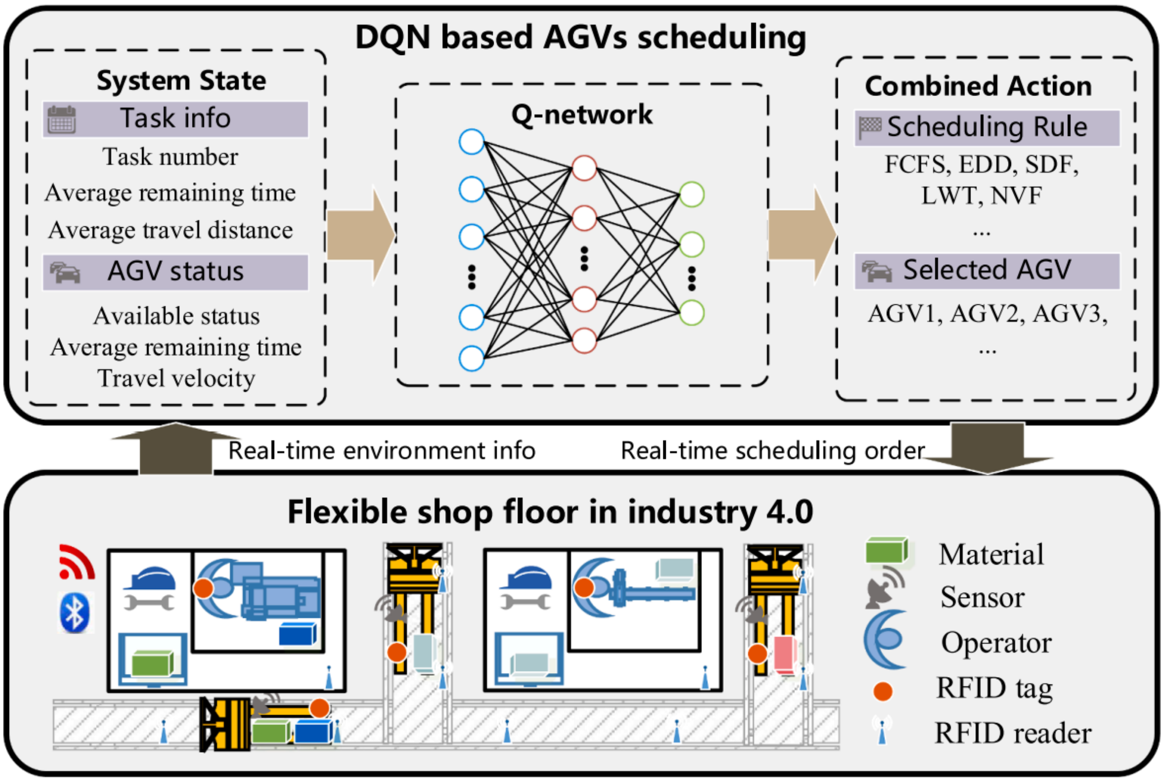


Figure 20: Architecture of AGVs real-time scheduling approach using DRL (Hu et al., 2020)

Another solution is proposed by Bányai, T. (2021), who described an autonomous guided vehicles-based in-plant supply in a cyber-physical environment, including assignment, routing, and virtually scheduling (showed in Figure 21).

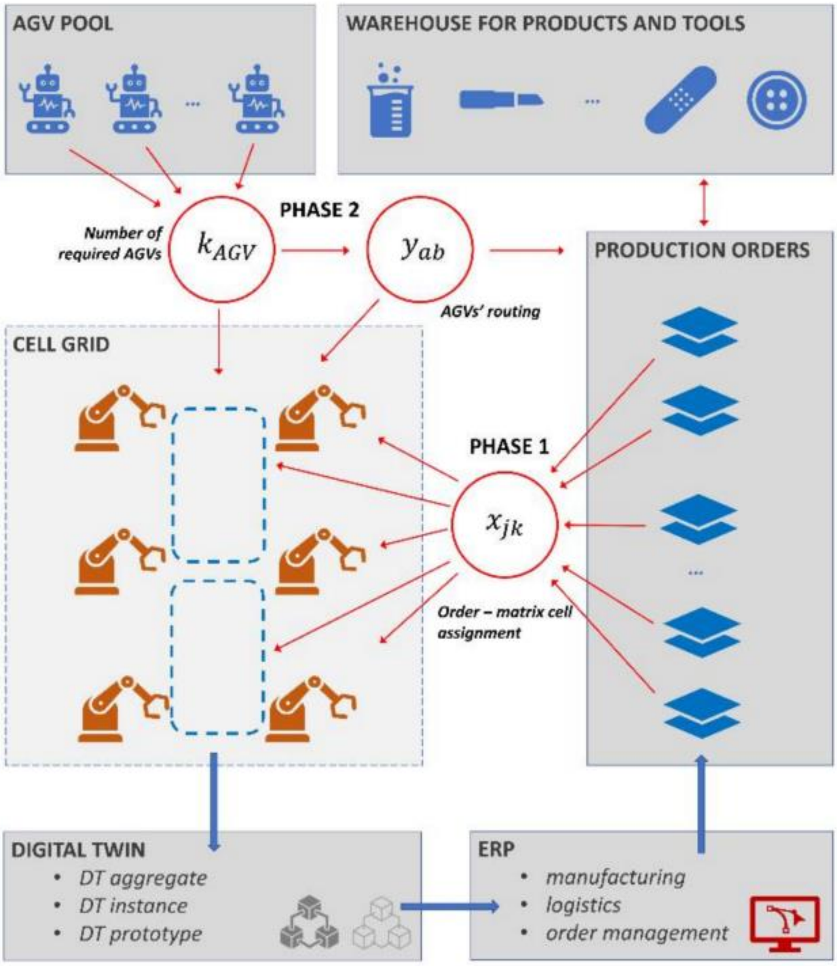


Figure 21: Integrated model of assignment and routing problem in a cyber-physical manufacturing environment (Bányai, T., 2021)

The model refers to the so called "matrix production", which is a new solution proposed by KUKA AG (one of the world's leading specialists in automation) that uses various Industry 4.0 technologies transforming conventional manufacturing intro cyber-physical manufacturing. In a matrix production system, standardized configurable production or assembly cells are arranged in a grid layout. Manufacturing and logistics are separated and fully automatized.

The model proposed in the article has two stages. Phase 1 includes the assignment of production orders to the grid cells. Production orders are generated by the ERP, which can work thanks to all the data coming from the sensors and data collection units of cyber-physical environment through a digital twin solution, that makes it possible to make real time analysis, controlling, and forecasting. Phase 2 includes the routing of AGVs available in the AGV pool, that considers either the minimizations of required AGVs or the minimization of energy consumption.

The results of this approach can be generalized because the model can be applied for different production environments.

A similar solution is proposed by Bányai, Á. (2019), which can be divided into two main parts: the first part is the extended scheduling based on ERP data, while the second part, the real-time scheduling, is based on information from the cyber-physical environment and includes routing and scheduling of clustered supply-demands and rescheduling and rerouting of matrix cell's supply in order to insert new supply-demands (caused by malfunction of technology and logistics or caused by a new customer's order to be fulfilled). As Figure 22 shows, the architecture of the solution has many similarities with the one described above.

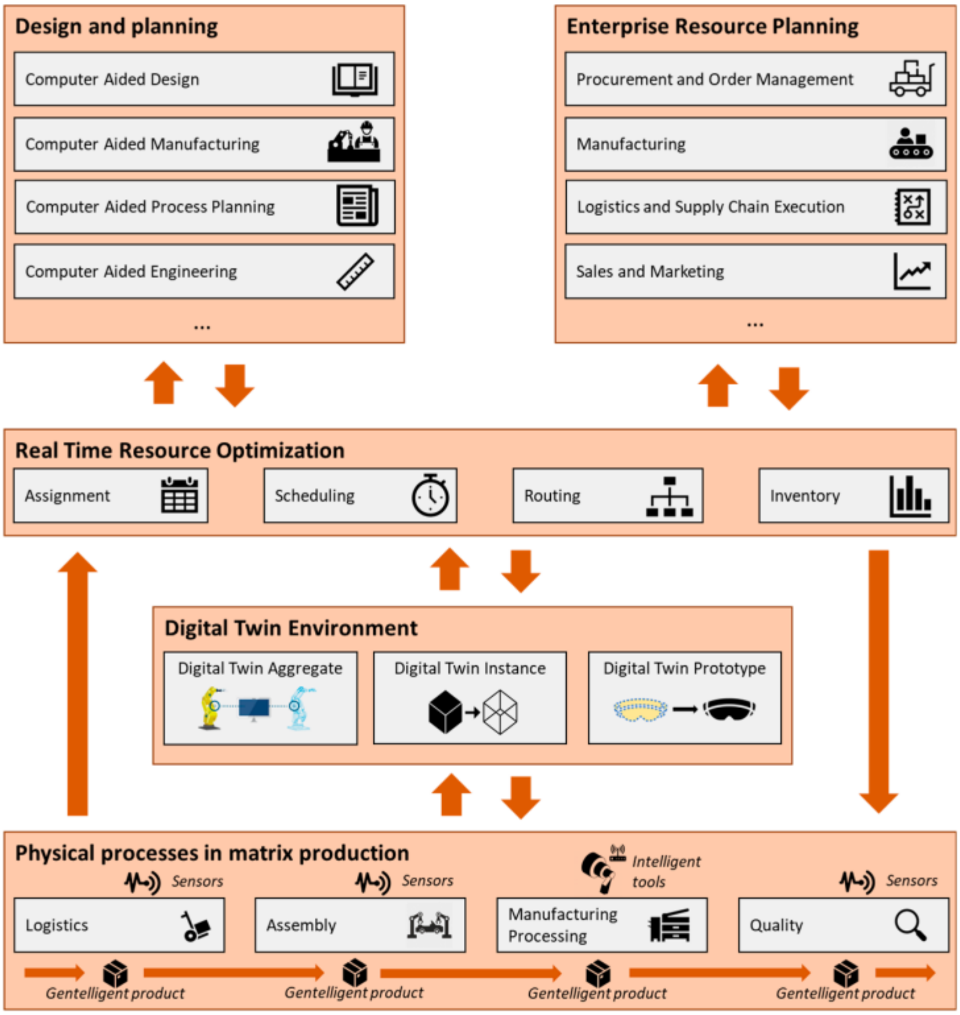


Figure 22: Structure of real-time resource optimization in matrix production (Bányai, Á., 2019)

A further example is given by Yao et al., 2020. They pointed out the need for IT tools to schedule/reschedule FMSs based on the integrated machine and AGV operations, in order to rapidly respond to various manufacturing disruptions and to operate in an optimal manner. This because of the complexity of FMS scheduling, as it does not only involve the job operation sequencing, but also the assignment of material handling tasks to corresponding AGVs by considering the arrival and departure time of vehicles and possible interferences.

The paper presents the Smart AGV Management System (SAMS) aiming to integrate real-time shop-floor monitoring and analytics systems with production schedules of machines and AGVs (Figure 23 describes the solution in detail). The system uses IoT-enabled production data to enhance the accuracy of the digital replica of the FMS under consideration. In the event of a manufacturing disruption, the system automatically detects the production anomaly and releases a set of re-scheduling strategies aiming to satisfy both maximised just-in-time delivery performance and minimised AGV energy consumption on time.

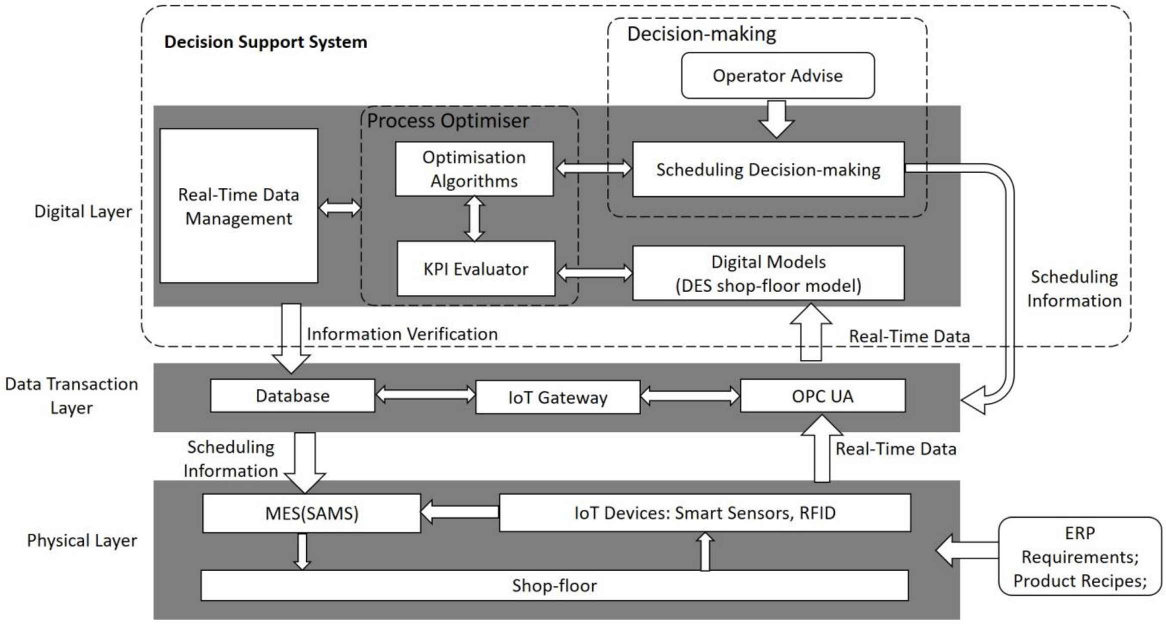


Figure 23: SAMS architecture (Yao et al., 2020)

Given these dynamic solutions that use digital technologies, and considering the reasoning made in the previous paragraph, it makes sense to ask whether the existence of a dynamic scheduling is bound to Logistics 4.0.

Of the 59 articles considered, 48 do not refer to Logistics 4.0. Of these, 17 use a dynamic approach. Therefore, dynamic solutions can clearly exist independently of digital technologies. So, is there a difference between "traditional" and "digital" dynamism?

Choi and Lee (2002), with their solution that according to them is valid regardless the automation level of the transporter, defined as “static” a part-feeding system in which a plan is made once a day and it is not changed without the intervention of control personnel. Conversely, in a “dynamic” scenario the part consumption amounts are considered hourly, considering the actual production progress. The solution is based on the identification of the parts to be fed and the estimation of the feeding amounts based on consumption rate and inventory level.

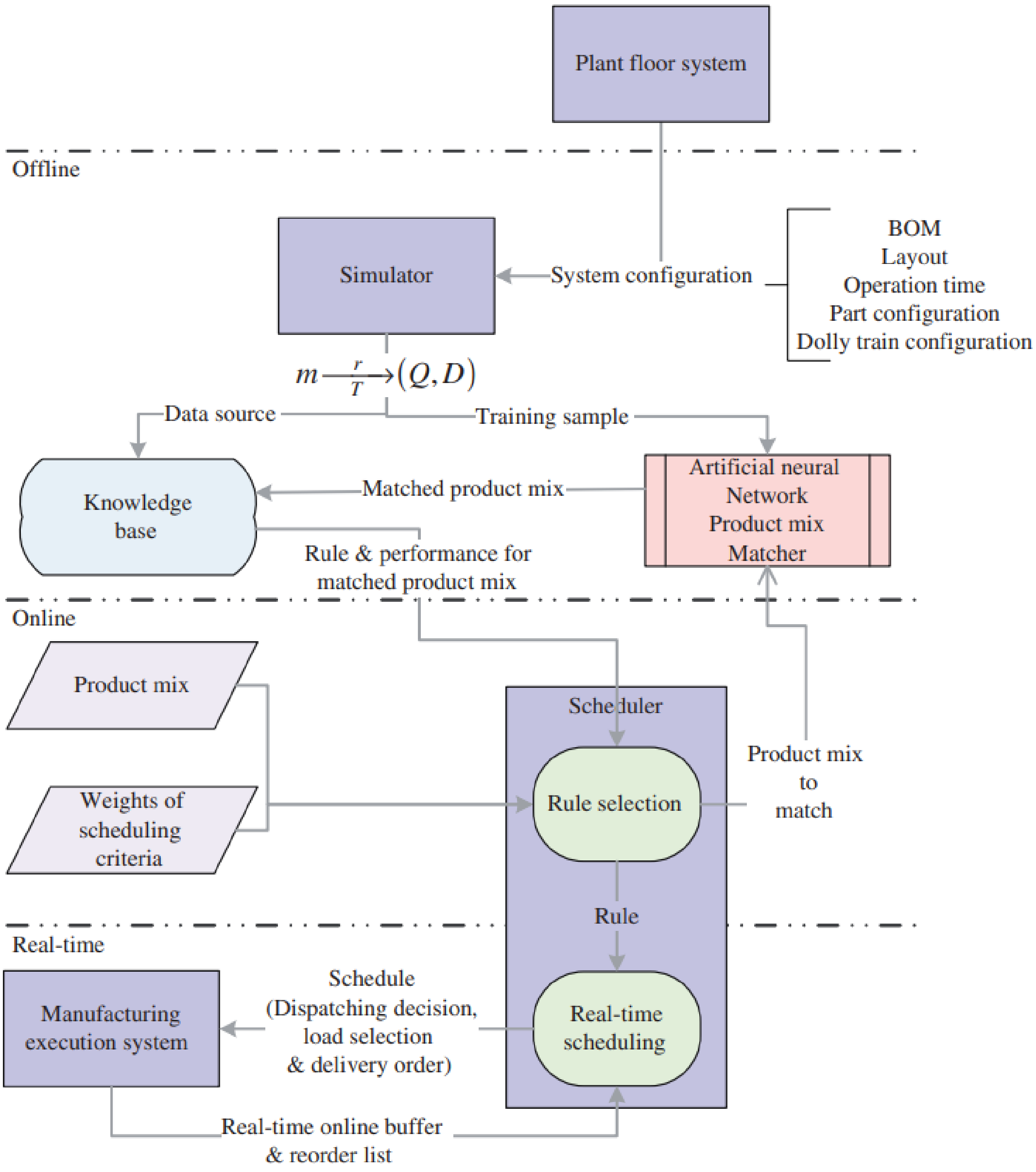


Figure 24: Multiple-criteria real-time scheduling structure (Chen et al., 2011).

Another example of dynamic scheduling is provided by Chen et al. (2011), with their multiple-criteria real-time scheduling (MCRS) approach (Figure 24). It consists of three phases: offline knowledge base (KB) building and machine learning, online rule selection and real-time scheduling. In the offline phase, a set of rules is tested via simulation and the results are collected to build a KB and to train an artificial neural network (ANN). The KB and the trained ANN are then used in the online phase to select appropriate rules based on the product mix and the weights of the scheduling criteria. In the last phase, the selected rules are applied in real-time scheduling.

The results show that MCRS can select optimal rules dynamically in most cases, and that the performance of MCRS greatly depends on the static rules themselves. When a few static rules dominate the others and the performances of the dominated rules are similar, MCRS only performs a little better than the best static rules. Other aspects, such as using other machine learning approaches instead of ANN, taking not only the product mix and the weights of the criteria but also other factors into account, utilising knowledge during online production, incorporating more rules, etc., are not discussed in the paper.

As described in the first article, and in general in all those contexts without a continuous collection of information, a scheduling can be "dynamic", but in those scenarios the difference between static and dynamic lies only in the time interval between two data collections and between scheduling and rescheduling. It is also difficult to establish a threshold that distinguishes the two approaches. Dynamism cannot be linked to an arbitrarily chosen threshold.

Another aspect that emerged from the two examples of dynamic scheduling described above is the following: the only factor that is taken into account to trigger a rescheduling is production, in terms of volume or mix. Other variables that can create deviations from the initial forecasts are therefore ignored, such as congestion problems, vehicle breakdown, etc.

The difference between the concept of traditional and digital dynamics becomes therefore clear: the second consists of a real-time approach which takes into account all the relevant variables.

5.2.3. DISPATCHING

A novelty enabled by Industry 4.0 in this field consists in allowing mobile robots to be close to the point of demand before an actual need is announced. This, according to Fregapane et al., 2021, can increase performance: "The increased flexibility of accessing a wide area and of free positioning due to autonomous navigation, enable new opportunities for positioning and for cruising while an AMR is idle. Centralizing the decision-making processes of distributing and dispatching AMRs requires a system that analyses the AMR positions and the demand data. ML and big data analysis of demand can support the optimization of vehicle distribution over the system. However, large-scale AMR systems need high computational power to analyse and communicate in real time. Decentralizing this process will decrease the need for high-power cloud computing. Each AMR will optimize its available time based on historical data and on data shared with neighboring AMRs. Continuous communication and negotiations will optimize the AMR's ability to react quickly to demand".

5.2.4. ROUTING

Path planning, or routing problem, consists in identifying the shortest and conflict-free path. With AMRs or new AGVs that can move freely and autonomously between locations, a robot can hypothetically create a new path each time.

In case of static planning, this problem is solved only once, but dynamic scenarios can require this process multiple times.

A good example of development of coordination of multiple-robots system is provided by Cecchi et al. (2021), who presented a distributed method for coordinating heterogeneous fleets of autonomous robots with the aim to define a coordination algorithm which leverages local inter-robot communication to compute and revise the robot trajectories so that: (i) collisions between robots never happen (safety); (ii) all robots achieve their destination in finite time (liveness); (iii) the solution is general to robots and robust to uncertainties in trajectory execution.

5.2.5. ROBUSTNESS AND RESILIENCE

A crucial attribute of autonomous systems is the ability to operate without human surveillance or interference and to recover after failures and changes, guaranteeing a robust and resilient system. System robustness is defined as a system's ability to remain functioning under disturbances, maintaining desired characteristics. System resilience is the ability to return to normal operations over an acceptable period of time, after those disturbances. This implies that information is needed on how the system responds to different degrees of disturbance. This feature gives rise to a new descriptive variable, which is precisely the ability of the system to work and without human intervention in dynamic conditions. Among the articles considered in this SLR, only few of them pointed out this feature. Nevertheless, Fregapane et al. (2021) considered this dimension as really relevant in the new context enabled by digital technologies. Furthermore, also in their article is written that only a few studies have evaluated the ability of AMRs to respond to reliability issues, and that dynamic interactions by humans are often neglected in simulation studies.

6 FUTURE RESEARCH AGENDA

Considering what was discussed in this SLR, the analysis of the current solutions' characteristics and the impact of Logistics 4.0 on them, a future research agenda is suggested below.

- RELEVANT DIMENSIONS: for what concern the dimensions of the current approaches, considering the gaps identified during this SLR, the future research directions should be:
- Multi-objective optimization of AGVs real-time scheduling considering more objectives such as energy consumption, equipment utilization, maintenance cost, etc. (Hu et al., 2020). Although many goals are connected to each other, the simultaneous optimization of those that do not affect each other and the addition of new goals such as those listed above are now possible with Logistics 4.0.
- Simultaneous inclusion in the solutions of all the constraints necessary to make the approaches feasible: capacity and time windows, but also other emerging aspects, like battery capacity for instance (from literature review of Lee et al., 2021, there is no published research that combines the EF routing problem with the battery charging scheduling problem considering EF operational performance (i.e., total travel distance and EF idle time for battery replacement) and energy performance (i.e., energy cost)).
- Development of solutions considering dynamic transfers, as suggested by Boden, Rank and Schmidt (2020), and further quantitative researches on the possible improvements in efficiency coming from them. Thanks to Logistics 4.0, re-auctions (Rivas and Xirgo, 2019) are allowed while a vehicle is already performing its task, and it is possible to reassign the order to a different vehicle if this change allows to improve the objective function.
- Development of faster heuristics as well as specialized exact methods. Solutions suggested, such as the decomposition approach of Emde and Gendreau, 2017, may also form the basis of such an exact procedure.
- Development of dynamic solutions that both considers MHS and production systems. The importance of both the dynamic nature of a solution and its wider scope is well explained by Chen et al. (2011): "the product mix can have a great impact on material handling, since assembling different products usually requires different part types. Therefore, the product mix cannot be ignored in multiple load carrier scheduling. Also, because of the dynamic nature of the market environment, the weights of the scheduling criteria may vary significantly".

- LOGISTICS 4.0: the articles that addressed the design and control problems of the manufacturing system and their material supply problems are focusing on conventional manufacturing, and only few of them describe the logistic problems of cyber-physical manufacturing. Therefore, this research topic still needs more attention and research. Considering the new possibilities enabled by Logistics 4.0, the future research should focus on:

- Evaluation of the number of vehicles, considering the new set of tasks that can be performed by the vehicles (hence, also the different types of vehicles within a fleet) and the dynamic environment in which they operate. The identification of the optimal number of vehicles has been poorly studied in the publications considered in this SLR, and the possibility of carrying out other activities in addition to pure transport complicates the problem even more.
- Evaluation of which decisions should be centralized and decentralized and what degree of autonomy should be given to the vehicles (Fregapane et al., 2021).
- Development of distributed deadlock identification and prevention/repair strategies, traffic-aware motion planning, and testing of routing problem solutions with real robots (Cecchi et al., 2021), in order to fully exploit the potential of Logistics 4.0 in routing problems and also improve dispatching of vehicles thanks to their positioning while they are idle.
- Research on system robustness and reliability. New simulation models may support the autonomous decision-making processes when AMRs fail. AI techniques such as ML can support AMRs to react dynamically and independently without human surveillance in case of failures. These capabilities enabled by the Logistics 4.0 should be further investigated, to quantify the system robustness and reliability.
- Measurement of the impact that each Logistics 4.0 principle on overall MHS performance, for instance in terms of: reduction in costs related to the transport of parts activity, reduction costs related to integrated scheduling of more processes combined, better performance (time, quality) enabled by better collaboration among different players of the supply chain.

Moreover, Fregapane et al., 2021, stated that it is still difficult to estimate the benefits that AMRs will bring and to determine how they should be deployed to obtain maximum benefits. AMRs are a useful example of technologies that incorporate some of the innovations brought by Industry 4.0. Generalizing the discourse, it can be said that it is still difficult to estimate the benefits that can arise from the application of all the Industry 4.0 technologies. In addition to the impact that can be obtained from the technologies, the benefits that dynamic (rather than static), decentralized (rather than centralized) and integrated (rather than just focused on MHS) approaches in general can give need to be quantified. Only a few studies have investigated the conditions under which those characteristics make a solution more profitable, or results in higher performance.

- Investigation of the role played by different players in driving the Logistics 4.0 transition process, by identifying who can lead the change and which organisational levers can drive the change management process (Modica et al., 2021).

In conclusion, although research is growing rapidly, several research areas have still received little attention (some of them because of their new increased relevance, given the possibilities enabled by Logistics 4.0), leading to a long future research agenda.

7 CONCLUSIONS

A MHS aims to deliver the right raw materials and semi-finished parts, in the exact quantity, at the right location, at the right time while maintaining the specific sequence of material delivery (Rahman, Janardhanan, Nielsen, 2020). Due to exorbitant product variety, very limited space, and other factors, organizing efficient and timely deliveries of materials and parts is one of the most pressing problems of modern mixed-model assembly production (Emde, Gendreau (2017). This complexity is partially brought by the transition from mass production to mass customisation. Nowadays customers prefer highly customized products, which leads to a need of change: from traditional production paradigm, where highly customized products are associated with high production cost, to mass customization, where production cost can be reduced while maintaining product quality and on-time delivery to satisfy diversified demands (Nielsen et al., 2017).

Furthermore, nowadays companies operate in a context deeply affected by the technological push brought by the Industry 4.0.

Through the review of the existing literature, this SLR investigated two Research Questions (RQs):

RQ1. *What are the relevant dimensions used to describe the task assignment process for a fleet of vehicles feeding production systems?*

RQ2. *How does the implementation of Logistics 4.0 principles affect the task assignment?*

To answer RQ1, firstly an overview of the general problem of transport of parts has been given. Subsequently all the variables that influence and distinguish different contexts and approaches were identified.

- Objectives: the aims that lead the solutions, which typically can be (i) max throughput, (ii) min earliness/tardiness, (iii) min time, (iv) min distance, (v) min number of vehicles, (vi) safeness, (vii) min energy consumption.
- Constraints: the set of variables taken into account when designing the solution, which typically can be (i) time window, (ii) capacity limit, (iii) single/multiple stations that can be visited in a single mission.

- Fleet capacity: surplus capacity must be avoided for both economic reasons and congestion problems, as well as insufficient capacity, because of the impact on throughput.
- Problem faced: they can be classified into (i) dispatching, (ii) routing, (iii) scheduling.
- Exact/Heuristic solution: exact algorithms are applied to find solutions and prove them to be exact, but they are strongly restricted in problem size, heuristic approaches are used to calculate solutions for more extensive problems even giving up a global optimum.
- Centralized/Decentralized approach: in centralized approaches there is one single decision-making entity that collects global information on the fleet, while in decentralized solutions robots can autonomously decide their future actions based on local information.
- Scope: simultaneous scheduling consists in simultaneously considering production system scheduling and the scheduling of the MHS, to exploit the interactions between them; while in an independent scheduling the scope is limited to the MHS, while it simply takes the scheduling of other processes as input data.
- Static/Dynamic: static scheduling approach usually assumes that all the task information is stable and obtained in advance, and then establish an analytical model and solve it; dynamic scheduling instead takes into account data taken during the process and update the scheduling.

Important considerations were made.

Concerning the considered constraints, only 17% of the articles considered “allow” the vehicle to visit more stations in a mission. Time window and capacity limit were definitely more considered, but only 32% of solutions consider them simultaneously.

The most common goal is to minimize time, which, as it is linked with the distance minimization, earliness/tardiness minimization and throughput maximization, can be expressed through these other three objectives. The objective regarding the energy consumed reflects the safeguarding of the environment and saving costs, and is also affected by the minimization of the number of vehicles.

For what concern the problem faced: routing is the least discussed (partially due to the fact that many solutions assume a pre-defined path for robots, that are not free to move on the shop floor), while dispatching and scheduling are more treated and seem to be linked.

The exact solutions are much less than the heuristic ones, due to the NP-hard nature of the problem, that makes the exact algorithms exponentially time consuming when the number of vehicles and the variables included increases.

Control framework dimension is very unbalanced, with very few decentralized solutions. This dimension seems to be affected by other two, since all decentralized approaches are purely dynamic and limited to MHS, neglecting other processes. This is not true for centralized approaches.

Another highly unbalanced situation is that concerning the scope of the problem (if limited to the MHS or extended to other processes of the production system as well). Researchers have studied these problems mainly separately, assuming them independent.

These statistics suggest that there is a gap between the theoretical research on the assembly line balancing problem and real-world application.

For what concern the RQ2, a definition and description of Logistics 4.0 has been firstly provided. Subsequently, the impact of this phenomenon on the task assignment problem has been discussed. The technological advances of Logistics 4.0 have significantly helped to achieve operational flexibility and to increase performance in productivity, quality and cost efficiency. Taking decisions autonomously thanks to AI promotes the decentralization of activities. Real-time data collection and interconnection of all the actors in the plant also allow to schedule both production process and material handling activities, not as independent entities. The problem can often be addressed rapidly, enabling a dynamic approach, without unrealistically considering the context stable.

Lastly, a future research agenda has been suggested.

■ For what concern the dimensions of the current approaches the future research should focus on:

- Multi-objective optimization of AGVs real-time scheduling considering more objectives such as energy consumption, equipment utilization, maintenance cost, etc.
- Simultaneous inclusion in the solutions of all the constraints necessary to make the approaches feasible.
- Development of solutions considering dynamic transfers and quantitative assessment of their impact on the efficiency of the system.
- Development of faster heuristics as well as specialized exact methods.

- Development of dynamic solutions that both considers MHS and production systems, not dealing with them as independent entities.

■ Considering the new possibilities enabled by Logistics 4.0, the future research should focus on:
- Evaluation of the number of vehicles, also considering the new set of tasks that can be performed by the vehicles.
- Evaluation of which decisions should be centralized and decentralized and what degree of autonomy should be given to the vehicles.
- Development of distributed deadlock identification and prevention/repair strategies, traffic-aware motion planning, and testing of routing problem solutions with real robots.
- Assessment of system robustness and reliability, since they can work without surveillance.
- Measurement of the impact that each Logistics 4.0 principle on overall MHS performance, as it enables the achievement of decentralization for instance, but the conditions under which this kind of solution more profitable, or results in higher performance, are still to be identified and quantified.
- Investigation of the role played by different players in driving the Logistics 4.0 transition process.

This SLR presents both academic and practical implications. To the best of author's knowledge, this research is one of the few studies that aims at classifying the task assignment process for a fleet of vehicles feeding production systems, highlighting its relevant dimensions and providing a complete framework.

As a result, researchers can now have a clearer framework that explains how multiple decision variables affect the task assignment process. These dimensions, in addition to distinguish the various types of systems, can also be decisive in helping practitioners during the design of a specific solution, as they play the role of a list of decisions to be made.

Moreover, an analysis about the impact of digital technologies on the intralogistics field, in detail the transport of parts, has been carried out.

The findings of this work prove that the problem of part feeding and the impact of Logistics 4.0 are complex topics and represent a vast research field yet to be fully explored.

This work contains some limitations, the main one being related to its conceptual nature. Empirical research with quantitative studies on the performance of MHSs, in every possible configuration and scenario, would be useful to create a complete knowledge of this topic.

Given the nature of the SLR, another limitation is given by the query strng. A greater focus of keywords on concepts such as Logistics 4.0 and its technologies could help to explore this field more fully.

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List of Abbreviations

ABBREVIATION	**DESCRIPTION**
AGV	Automated Guided Vehicle
AI	Artificial Intelligence
AMHS	Automated Material Handling System
AMR	Autonomous Mobile Robot
ANN	Artificial Neural Network
APT	Actual Processing Time
DQN	Deep Q-Network
DRL	Deep Reinforcement Learning
EF	Electric Forklift
ERP	Enterprise Resource Planning
FAFS	First Available First Selected
FMS	Flexible Manufacturing System
GS	Global Scheduler
IoT	Internet of Things
KB	Knowledge Base
LIAT	Longest Inter-Arrival Time
LIT	Least cumulative Idle Time
LRD	Longest Rectilinear Distance
LWT	Longest Waiting Time
MCRS	Multiple-Criteria Real-time Scheduling
MHH	Material Handling Holons
MHS	Material Handling System
MIT	Most cumulative Idle Time
ML	Machine Learning
MLT	Manufacturing Lead Time
MRIQ	Maximum Remaining Incoming Queue space
MROQ	Minimum Remaining Outgoing Queue space
OH	Order Holons
PLC	Programmable Logic Controller
RH	Resource Holons
ROI	Return On Investment
RQ	Research Question
SAMS	Smart AGV Management System
SM&DB	System Monitoring & Database
SRD	Shortest Rectilinear Distance
TO	Transport Order
WIP	Work In Progress

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