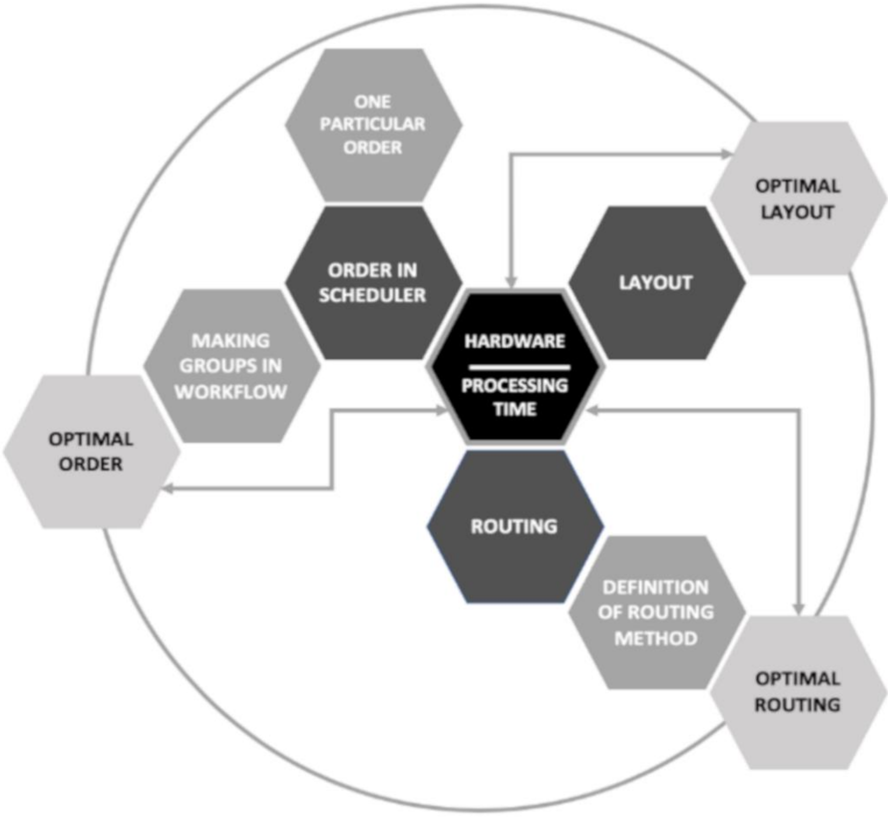

OTTO VON GUERICKE UNIVERSITY MAGDEBURG

Conference Proceedings

14th International Doctoral Students Workshop on Logistics

22 June 2021, Magdeburg

Institute of Logistics and Material Handling Systems

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

14th International Doctoral Students Workshop on Logistics

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Table of Content

Foreword

Dear Ladies and Gentlemen,
Colleagues and Friends,
We are pleased to present the proceedings of our 14th International Doctoral Workshop on Logistics. In recent years, our workshop has been a constant in ever-changing times. For the second time, we are forced to move the scientific exchange to the digital realm. But scientific progress nourishes our hope: effective vaccines have been developed in a very short time. Thus, science is helping to ensure that we can soon return to normality. But are we simply returning to the before or has our normality changed? Will digital tools continue to be used as much? How is public life changing in our cities? As scientists, we support society in answering these and other questions.
Many things have also changed for our discipline of logistics. While the digitalization trend has experienced some acceleration, other trends, such as the Global Division of Labour, are increasingly being challenged. How resilient are global value chains? What risks exist due to more frequent pandemics or severe climate changes? Through our daily research and education, we try to contribute to solutions for these challenges.
This workshop also contributes: doctoral students have the opportunity to present their topics and discuss their questions with experts - this strengthens the education of young researchers and, in the long term, research itself. And the pandemic has shown us the importance of an excellent science system.
This year we are trying to further expand the discussion opportunities in our digital format. Furthermore, we would like to increase the visibility and findability of the contributions through a digital open access publication of the proceedings.
As every year we are happy about our international participants, who come from Cuba, Hungary, Ukraine, Austria, France and Germany. Their exciting contributions give us insights into the application of methods and models in new contexts, present exciting technologies for production or transport or show us logistical answers to our global challenges. The contributions show the individual research questions and provide an interesting insight into the numerous international organizations. We wish our readers many new impressions and look forward to welcoming you at the 15th International Doctoral Students Workshop on Logistics 2022. We are sure looking forward to see you here in Magdeburg next year.
Sincerely,

Prof. h. c. Dr.-Ing. Dr. h. c. (UCLV) Elke Glistau

Prof. Dr.-Ing. Sebastian Trojahn

Scientific Papers

Automated navigation system for a marking machine

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Abstract

The research is devoted to the development of a navigation complex for an autonomous self-propelled machine and a program managing to it. The developed sensor system continuously transmits the necessary data for management and controls the traffic markup process, according to the specified parameters. Due to this road markup, you can perform automatically quickly and clearly.

Despite the large number of manufacturers of such equipment, there are still unresolved issues of full robot process.

1. Introduction

Time, when people put a road markup, has long expired. Today, for this purpose, road markup machines are used. They are able to work fast, qualitatively and practically without breaks. Today, these vehicles are used where it is necessary to provide secure traffic and people.

In the modern world, the requirements for road markings are quite strict. Today, the technical level of marking machines allows many operations for drawing a road markup automatically. They are equipped with not only devices for automatic temperature adjustment, but also where autonomous control devices are marked.

Most often, road markup equipment is divided into three groups: manual, self-propelled and trailed [1, 6]. The first group usually includes hand markers of road markers, as well as equipment for road surface preparation to further work. Self-propelled vehicles are most often built on the basis of a car chassis [2, 7]. When performing small volumes of work use trailer equipment for road markup.

By the type used markup of road marking machines are divided into two categories - simple paint and varnish machines and machines that can work with thermoplastics [3].

2. Methods

The research is devoted to the development of a navigation system for an autonomous self-propelled machine, with which a road markup can be applied faster and more correct. The sensory system has been developed to monitor traffic marks. This system continuously transmits data and manages the traffic marking process according to the preliminary setting of the parameters. Thanks to the developed sensory system, the efficiency of the marking machine has improved significantly, and its value has decreased compared to analogs.

To simulate the system of naving and autonomous management, a fundamental model of the machine (Fig. 1.) was developed from: 1-bearing frame; 2 - control system; 3 - power system; 4 - technological complex with paint; 5 - a near-paint system; 6 – a distant-paint system.

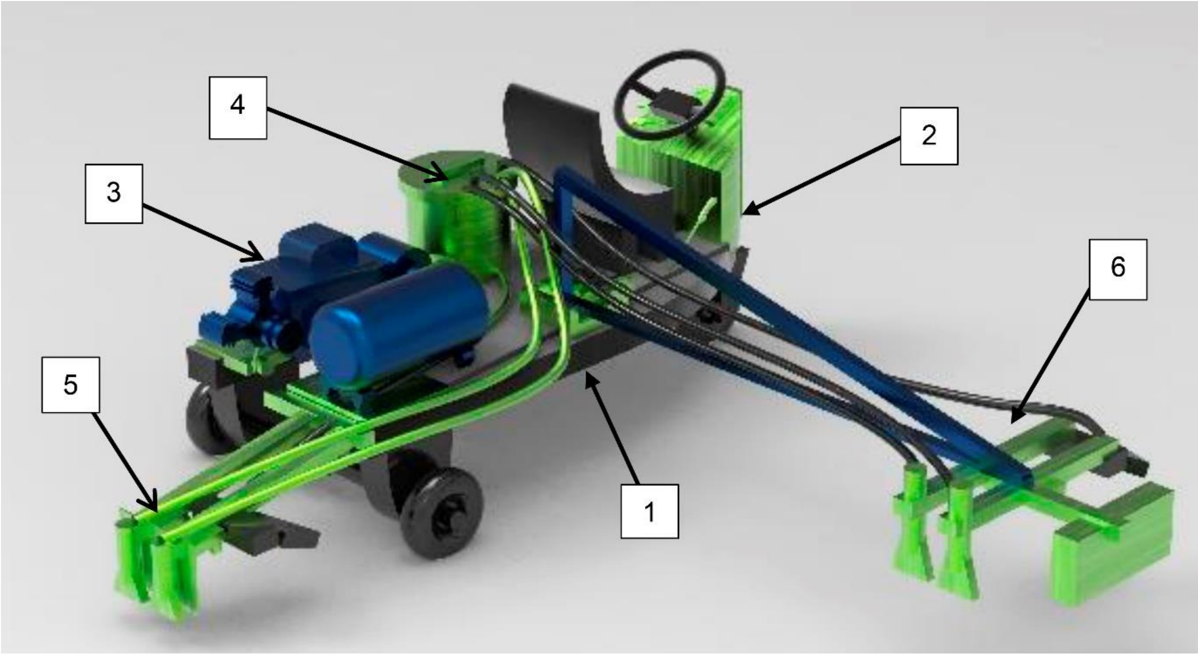

Figure 1: A principal model of the measuring machine

In this paper, the experimental development of the navigation system for an automated self-propelled machine is considered for a road marking. In general, the system consists of two systems of individual systems: the internal control system and the external navigation system. The internal system consists of a system of sensors and a machinery located on the machine. The external system is based on GPS observation technologies. To date, GPS technologies are an integral part in many spheres of activity. The navigation capabilities of observation systems provide invaluable assistance in the search and control of the necessary facility.

2.1. External navigation system

In general, GPS observation systems are distributed to systems with static positioning and kinematic. Static positioning allows you to accumulate data, seeking an increase in accuracy. The advantage of kinematic positioning is its ability to receive a vehicle trajectory, which has a satellite apparatus.
To solve our task, we choose kinematic. The equipment necessary for the implementation of observation varies in architecture, the method of action, purpose, accuracy, value and other parameters. The best GPS tracker Senseit GT13 is best suited to us because it has proven a simplified management and price. The SENSEIT GT13 tracker will allow the continuous on-line monitoring of the movement of the machine as well as if necessary, control its entry and exit with a given geozone. The use of SENSEIT GT13 will be comfortable for operators - the tracker has a compact size and weighs only 57.5 g. And the presence of the SOS button will provide additional security in emergency situations: When you work the object coordinates of the location of the object are transmitted to the registered e-mail address.

2.2. Sensor system for positioning machine on the road

The internal control system consists of a certain set of sensors and control devices. The sensor system is needed because they can ease some moments of the location of the machine in the middle of the road, because the GPS system works not exactly. To do this, we will use sensors such as laser, motion sensor and gauges sensor.
The motion sensor on the road (Fig. 2, 3) is necessary because this principle will be applied with a road marker, and will be fixed.
Deal HC-SR501 Motion - Piroelectric Passive Infrared Sensor, Sensor. It reacts to the presence during the time the object is in sight. In a way, the DNA sensor has a longer signal maintenance. A duty can be preached in two operating modes (L) and without restart (H). The mode without restarting implies that the LED is burning not permanently, and it turns out and turns off when the object is found in the field of vision of a duty, the mode with a restarting is a member of the opposite.
For correct operation, you can not place a duty so that direct rays of light, in places of rapid temperature change, were made. There were protective lights (Fig. 4).

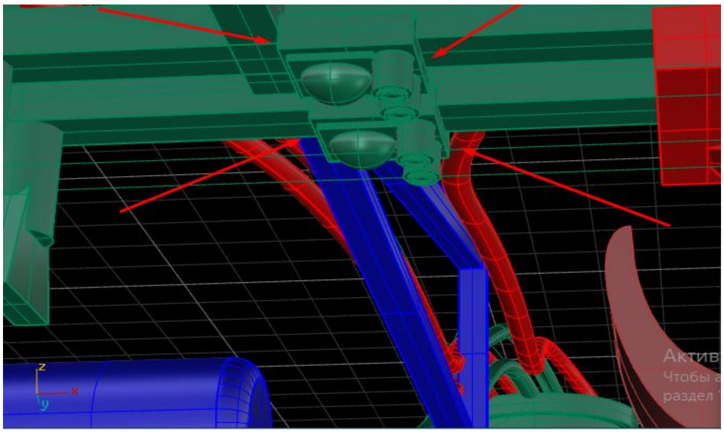

Figure 2: Location of motion sensors on the arrow

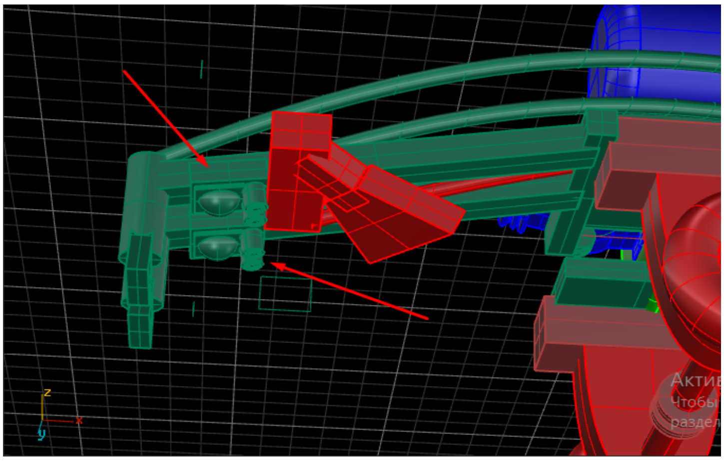

Figure 3: Location of motion sensors by car

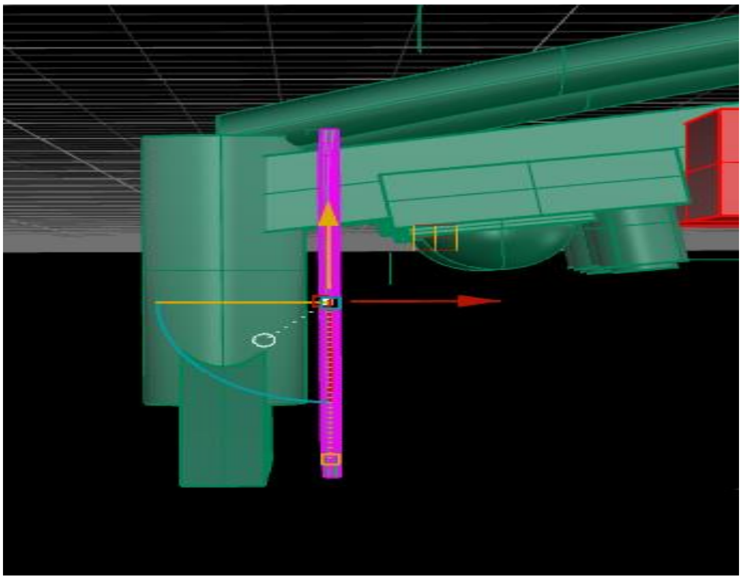

Figure 4: Protective screen from paint

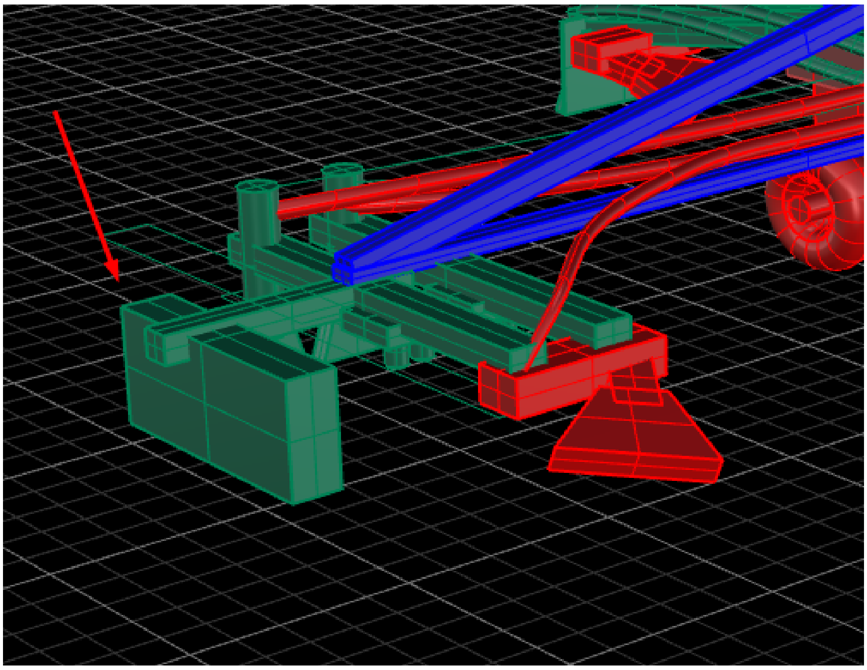

Figure 5: Location of the laser sensor

Laser Landscape Sensor LS2D designed to read relief at low distances. This is needed to position our car on the road, and it will be the main advantage, because the GPS system can have failures. Location of the laser sensor shows on the figure 5.

2.3. Creating a controller control program

Creating a program was performed in Coocox CoIDE. CoIDE has a large number of libraries. These libraries can be connected for any controller that it can support. You can also tie a program for firmware to a microcontroller, and not to run a separate program all the time. For the correct realization of the goal, a block diagram of the process (Fig. 6) was developed. By which the managing program (Fig. 7) was written.

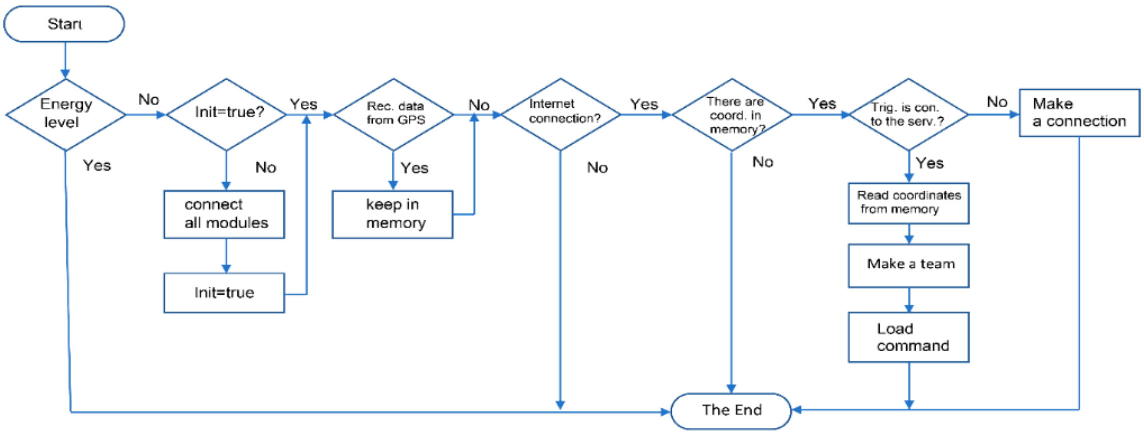

Figure 6: Block Scheme of the Managing Program

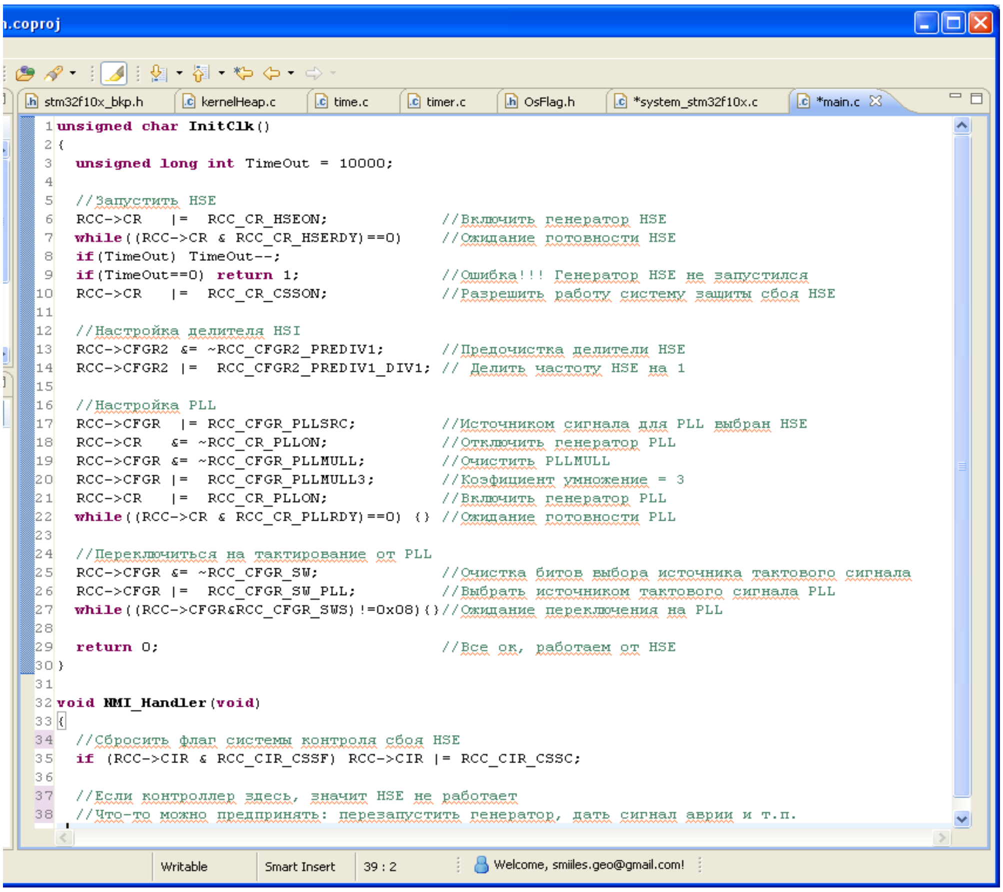

Figure 7: Program code

4. Results

Data experimental model of an autonomous self-propelled machine for drawing road markup solves a number of important issues. Enough software management will provide the required quality of all planned works. Thanks to the full automation of the entire complex, human work and factor of its influence will be minimized. This provides for a significant efficiency of its work as a whole.

5. Summary

The research and developed experimental model of the navigation system allowed compactly and easy to combine navigation and sensors. These systems have been software and hardware connected with automatic control of self-propelled machines for drawing road markup. Thanks to the developed sensory system and an improved program, the accuracy and autonomy of the marking machine has improved significantly, and its value has decreased, compared to analogs.

6. References

[1] DSTU 2587-2010. Road safety. Road marking. General technical requirements. Control methods. Rules of application [Electronic resource]: Access mode: https://manualov.net/

[2] Antipenko G., Kashevskaya E., Kostenko K. and others (2002): New technologies and machines in the construction, maintenance and repair of highways - Minsk: Design PRO, 224 p.

[3] GBN V.2.3-37641918-544: 2014 Automobile roads. Stored geosynthetic materials at road constructions. Basic demands [Electronic resource]: Access mode: https://ukravtodor.gov.ua/

[4] EATON 420 MOBILE PISTON PUMP CATALOG E-PUPI-TM002-E7 February 2020 [Electronic resource]: Access mode: www.eaton.com

[5] Kazubowski, R. Method and device to apply marks on the roadway surface. Robert Kazubowski, Tomas Krawczykowski, Jasek Osmalek. Patent WO2007027115A1·2007-03-08

[6] Kostyuk, G.; Fadeev, A.; Shyrokyi, I. (2011): Teaching Manual – Integrated manufacturing and comprehensive technological systems. Kharkov: National Aerospace university, 232 p.

[7] Kostyuk, G.; Baranov, O.; Shyrokyi, I. (2020): Teaching Manual – Construction of industrial robots. Kharkov: National Aerospace university, 136 p.

Ecological performance of past and present apple supply chains

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Abstract
The aim of the paper is to reconstruct typical German fruit supply chains of the past and the present. Basis for this is the definition of key areas to the supply chain and its ecological performance. The development of areas like: supply chain structure, players, locations and technologies/ methods are outlined and later on compared. For this purpose, scientific publications and available historical descriptions were used and subjected to a literature analysis. The research question is: Which conclusions for an ecologically designed fruit supply can be derived from the comparison of past and present practices in fruit supply chains?

1. Introduction

The climate and biodiversity crisis are dominant drivers for a holistic transformation of our society and economy. Consumption and production patterns need to fundamentally change in the near future to address our multiple crises.
Producing and transporting goods around the globe is the new – energy intensive - normal, even for agricultural goods which used to be produced close to us. Fruit supply chains are also international, shortening or regionalizing them can have quick ecological or economic benefits. Germany has relatively low self-sufficiency ratios for fruits and vegetables and high import rates especially from Mediterranean countries [1][2]. The alternative to a globalized, technologized and capital intensive agriculture industry is and agroecological development: it focuses on short supply chains, connecting local knowledge with high-tech- knowledge as well as using little chemical inputs [3]. An example could be the supply with organic, extensively grown apples, with old local fruit varieties using modern soil and weather analysis.
Every fruit product has an individual supply chain[4]: obviously for tropical fruits short supply chains are no option, but many other fruits like apples do have a potential for agroecological production and supply chains, which contribute much less to crises above.
Apples are easy to store and thus available throughout the year [5]. A big share of current conventional and organic apple production is located at the Lake Constance region and the Lower Elbe, with a proximity to agglomerations [6] and thus a potential for more sustainable supply chains. Supply Chain Management and logistics are essential for an efficient shipment of products from rural to urban areas – from producers to consumers [7]. The requirements for transport and storage increase with an growing distance between production and market [4]. To avoid product losses or quality deterioration, the logistics need to be timely, reliable, efficient and under the right and controlled conditions (humidity, temperature, levels of oxygen or carbon dioxide)[8][7].
The fresh logistics area is challenging due to scarcity of cargo space and truck drivers [9] but also because of sustainability or ecology of supply chains. Ecology in fruit supply chains is mainly connected to energy and material usage, logistics and its influences on biodiversity [10]. The product carbon footprint is one sustainability-oriented indicator, which shows the climate impact of a products supply chain (transport, packaging, storage) for its whole life cycle.
But sustainability is also seen as a driver for innovation and growth, even by conventional companies [10]. To achieve sustainability there is a need for management systems and indicators. The existing indicators can be grouped into three areas which also are the typical dimensions of sustainability: Economy, Ecology and Social Aspects, examples are transparency, social standards or water protection can be areas of indicators and sustainability management [10][11]. Climate aspects, as well as resource and energy efficiency are closely connected to logistics and will stay very important [10][12]. Different companies along the supply chain have a growing interest in indicators like the product carbon footprint and want to make their efforts towards a more sustainably supply chain visible [13]. The existing

indicators have a variety of shortcomings: difficulties to differentiate between products and supply chains, including the whole chain, being controllable, accepted and communicable at the same time [10][14] .
Looking at the food sector development there are some important trends like rising quality requirements, rising fruit consumption , centralization and convenience [1] [4] [11] [14] [15]. Ecological or sustainable production is another one [15], which is partly competing with the others. One of the trends which can be aligned with ecological goals is the trend for regionalization. Often it is connected with marketing [10], as it promises consumers to do engage in their region and to fulfil their wish for diversity [16] . Higher quality is often an argument for regional products [17]. Better storage opportunities make it easier to achieve regional supplies [5], which reduce the need for imports outside the season. The need for regional produced apples is so high the market is dominated by the demand [6]. Regionalization is a political aim to stimulate local economy and to reduce transportation [17], especially if regionality is defined by transport distances or short chains, rather than just being a marketing slogan. Farmers can work towards short supply chains to strengthen their position and retain more value from their products [17]. Short distances and regional production clusters facilitate information flow/sharing and market transparency [5]. From a research perspective there is a need for a better definition of regionality, as it can include regional products, regional processing or regional marketing [18][16] and is not necessarily defined by the realized transport distance.
Summing up there are various research opportunities:

- A political goal is to improve supply from and marketing structures for German/regional producers [19]
- A good definition of regionality and prove for its benefits is needed [4]
- Developing indicator systems, which integrate different perspectives and prioritizations, improve transparency, deal with missing data and help to overcome typical conflict areas (completeness/accuracy vs. feasibility; specific vs. comparable)[20][13]

While looking at the development of the fruit supply chain one realizes that aspects of a modern sustainable fruit supply have been the standard of past production patterns, i.e.: regional production and short chains, low chemical or energy input. [17]. The beneficial connection of regional production and consumption is an concept which originated in city planning during the last centuries [21]. The aim of this paper is, to compare present and past supply chains from a logistic perspective to find potentials for improvement of their ecological performance, therefore it is necessary to derive relevant indicators for the comparison and to use the findings to ecologically re-engineer our fruit supply.

2. Methodology

To find relevant information about past and present fruit supply chains a literature review was conducted using the Google Scholar search engine. The challenge is to find enough relevant data for an indirect survey of performance of the chains. The search terms used were "Obst Versorgungskette", "Obst Supply Chain" and "historische Obstversorgung". For this preliminary study no further terms were used to start with an overview focusing on general information and data availability for a basic Kuhn-process description (processes, structures, resources and steering systems). The found literature was read and reduced to the relevant sources, which answered at least one of the following questions:

- Structures/Steering Systems: How is/was the structure of fruit supply chains in Germany?
- Resources: What are/were relevant players and locations for the fruit supply? What technologies or methods are/have been used?
- Processes: Which processes are quantitively described and what information is available to derive indicators?

3. Results

The literature found was very diverse: study or research project reports, dissertations, scientific articles as well as historical articles or historical books were analysed. Most of the results related to modern supply chains, but relevant information was also found for the historical supply chains. While the sources about the present supply chains often cover few rather specialized aspects, the sources about the past supply chains draw a broader picture, which also results in a higher number of pages (Table 1).

Table 1: search terms, sources and their length

Search Term	Sources	Avg. Pages
"historische Obstversorgung"	4	206
"Obst Versorgungskette"	11	64
"Obst Supply Chain"	20	49

In the following sections the present and past fruit supply chains are described on the basis of: supply chain structure, players, locations and technologies/ methods.

3.1. Present Supply Chains

Today around two thirds of the German harvest are marketed unprocessed as (dessert)fruit, the other third is processed [22]. While mainly smaller enterprises produce the fruit, medium sized cooperatives etc. dominate the trade and large retail groups control the finale sales [8]. Mainly the imports consist of the fruits which are not produced in the country, but 15% of the imports still are apples due to seasonality [2] – fruit are mainly produced between June and November [14]. The German fruit production sector is strong because of good storage possibilities and a high demand for domestic products [5]. In the sector there is a tendency to business concentration, still because of the demand for alternative ways of production also many small companies are successful [17]. The supply chains are characterized by many actors and a diversity of marketing channels, although concentration is driven by the big retailers[2]. There are four main marketing channels, with different shares of fruit sales: direct sales 2 %, universal retail 31%, discount retail 50% and wholesales/others 17%[14] . Channels like direct sales, gastronomy and other big consumers will stay a niche [16]. Different way of direct sales for organic products are: Farmers markets and farm shops, Box schemes, Food co-ops, Specialized organic stores, Health food stores, Internet and mail-order, Catering services and farm restaurants [17]. The complexity of the handling of perishable products, as well as the complex trading rules are further attributes, which sometimes can be a barrier to enter the market [4]. Apples are the most produced and demanded fruit in Germany, Italy is the most important importer of apples [23][2]. The producer organizations are responsible for 50-60% of the total apple production, the acreage for fruit trees is slightly decreasing [19].

Locations: (ecological-) apple production is concentrate on historical grown productions regions, with a favourable climate and proximity to agglomerations, but also exists outsides these regions [6]. Lower Elbe and the Lake Constance region each produce around 30% of the total production volume [23], Lower Rhine is another important but smaller region [5]. The regions are successful because they allow short shipping times, the bundling of large amounts, economies of scale for storage, sorting, packing, etc. [5][24]. Food and fruit production seem to be more regional than commonly assumed [16]. The production, processing and marketing structures tend to be smaller in southern parts than in the northern and eastern parts of Germany [17]. Also the production volume and later on the stocks can vary strongly in their regional distribution [22].

Players: As mentioned before, the producers are mainly small companies, the majority with an acreage of less than 3ha. But the percentage of bigger producers growth, which results in a medium acreage of 5,2 ha in 2012 and is probably connected with the high yields of bigger producers[23]. Due to high usage of machines and workers bigger producers can have cost advantages, the production cost is between 350-450€/t. The concentration and the structural change can be witnessed as the majority of the producers are dependent from workers from outside the family [22].The small producers are often cooperating to gain a better position towards the purchasing of the trading companies even as competitors[5][6]. The producer organizations are the link to the trade with a challenging task to deal with the competing producers and the oligopolistic structures of the retailers [10]. Their responsibilities include the management of bundling, quality and risk, assortment, reliability for the buyers and storage, treatment and ensuring sales for the producers [19]. For organic apples most of the producers are organized in grower organization or similar marketing cooperatives – direct sales to wholesale or retailers play a smaller role [5]. The next step of the supply chain is the intermediate trade or wholesale. There are just a view people/companies responsible for the purchasing of fruit [4], the connections to the producers are very tight [6]. Today they are mostly responsible for packing, sorting and other logistics tasks, as many former task are nowadays done by the producers organizations[4]. Some wholesalers are trying to vertical integrate, while offering services like farming assistance to the growers [25] The main players of the chain are the large food retailers, the 10 largest retail groups amount for 90% of the revenue [4]. They normally have a relatively stable number of distributors on the upstream chain. [4] Because the supermarket chains have a growing interest in regional products, also marketing and processing companies are more engaged in that area [17]. Challenging for the supermarkets is the growing number of suppliers which is connected to the demand for regional products [26]

Technology/Methods: The intensive production is dominated by mechanisation and automation[27]. The selection of grown varieties is constantly changing and influencing not only taste an prices but also the production methods (i.e. pruning, harvesting) [22]. There is a lack of small and medium scale processing technologies [17]. From the production the fruit is normally transported to the warehouses, a continuous cold chain from producer to consumers is necessary [28] as most importantly the temperature but also the surrounding air (oxygen and carbon dioxide levels) are affecting biological reactions or microbial growth [7]. International transport is done in reefers containers. RFID, CAN, GPS or wireless technology allow monitoring and traceability. [28][29] Sensors using spectrometric methods or the electronic nose can help to control quality and fruit ripeness along the chain [27][30][31]. The regional and national transport is done by cooled trucks, sometimes with different cool zones for different product needs [4]. Lorry transport is preferred due to its flexibility [28]. Similar technologies are also used in the warehouses, where different temperature zones are integrated [32]. The use of artificial atmosphere (ultra low oxygen) in specific areas of the warehouse allows to store even very sensitive fruits [4]. Easy to store fruits like apples can be stored for the whole year, which reduces the needs for imports [23]. The retailers try to bundle their shipments over the warehouses [14], the usage of delivery time frames at warehouses and stores make an efficient transport and vehicle routing more and more difficult [9].

3.2. Past Supply Chains

In the 19th and early 20th century the total agrarian structure was fractured – fruit production played an important role for subsistence farming and an additional income for the farmers with a high valued product[33][33]. To reduce transport losses (and vitamin losses), as a sink to urban waste or for aesthetical reasons city planners wanted horticulture ad fruit production close to the urban areas [21]. Germany was globally one of the biggest fruit producers, with enough production for the national demand [34]. Still there was plenty of international trade and imports, for reasons like locally varying harvest, bad transport possibilities or storage opportunities [34].

Locations: A number of regions were formerly very important for the fruit supply: Lake Constance Region, Palatinate region, Rheingau, Taunus and Main River valley, Lower Elbe, Elbe Region in general, Lößnitz Region near Dresden, Werder along the River Havel or Guben along the River Oder[34].Their proximity to an urban market and the access to waterways were key locational factors [33], but also the near big water bodies could be used for irrigation, reflected a higher amount of sunlight and reduced temperature fluctuations [34]. Peripheral regions with a higher distance to the markets were more engaged in the production of processed, dried or canned fruit[33] [33]. Bohemia or Austria-Hungary were importing relevant amounts, partly because of varying national production quantities and prices, as well as favourable transport possibilities – sometimes abroad was more regional than other parts of Germany [34][34][34].

Players: The production of fruit and processed fruit products (liquor, dried fruit, wood for furniture and rifles) was done by small farmers or land folks as side business [33]. This was often done on extensive cultivations on common land, but also more specialized growers with intensive plantations and better fruit varieties were producing high quality fruits [33]. There were trading connections for local, regional and supra-regional markets, which were able to avoid fruit shortages [33][33], therefore one can assume companies for trade and transport were existent. The players in the retail part of the supply chain were very diverse: there was the classical weekly market, additionally market halls were built in larger cities at the end of the 19th century, which also had the function of wholesale. In industrialized areas there were mobile fruit sellers, selling lower qualities while in the cities specialized (tropical-)fruit shops came up, as well as fruit and vegetable shops [33].

Technology/Methods: The diversity of produced fruit variations was extremely high, which had various benefits: they were robust, with no need of chemical plant protection and longer storability without specialized technology to have fruits throughout the whole year. Also the fruits had a high acidity which allowed better processing. [35][34] But there were already activities by pomologist to select the better varieties for marketing, technical processes or uniform size and qualities [33][34]. Interestingly there was already a consciousness about the risk of huge monocultures and to little varieties [34]. New processing, conservation and storage technologies were supporting the growing fruit trade, important innovation were industrial jam production or heat sterilization[33]. Also alcohol, dried fruit and other fruit processes were industrialized, mainly in foreign countries the use of chemical food additives started [34]. Processes fruit made up a big part of the commercialized market [34].

For transport the water ways were extremely important, as they made it possible to transport fruit without packing and damage. Transport with trains was also possible but special packing was necessary and made it more expensive and needed more transport volumes [34] [34]. The additional cost for packing was estimated to be an 22% and made efficient use of the cargo volume more difficult[34]. The transport challenges is connected to the grown varieties as some old varieties are extremely pressure sensitive and had a shelf life of only 2-3 days[34]. Next to the development of steamships, the linkage to the railroad network was the most important transport innovation for

producing regions, as it both came with new marketing options [33].
To sum up: improvement of farm productivity (better variety, planning and cultivation), changing food habits, and technological innovation in transport or conservation were responsible for a very positive development of the fruit marked at the end of the 19th century [33] [34].

4. Discussion

Through the literature review a comprehensive qualitative comparison of past and present supply chains is possible, which is a novelty and not found in the literature. To analyse, compare or even improve logistical or ecological indicators of present and past supply chains, more quantitative data is necessary. Especially for the past chains this data is not found in the literature.
The first result is, that the ecological performance of past supply chains cannot be derived from the literature. The findings are general and only qualitative, like the fact regionalization of modern apple chains as well as the internationalization of past apple chains are both underestimated.
The modern supply chain is characterized by much more professionalization and concentration along the supply chains. This would make it relatively easy to analyse their performance. The past supply chains are much more difficult to describe or research because of their diversity and their fragmentation.
The second result is about regionality. While it is still necessary to further define the term "regional", it can only be ecological beneficial, if it is connected with short transport distances. Nowadays there are many different steps, players or marketing channels. A detailed analysis of transport distances not for the past nor today has been done. The biggest producing regions have a history which is reaching back to the past production structures, a proximity to urban areas and waterway connection, were essential for their former success.
Another finding is that some functions in the supply chain, which are today achieved with operators and technologies, formerly were achieved by certain methods and operations. For example modern technology makes long storage, transport and constant quality control possible. In the past transportability and over the year storability were increased by the selection of certain apple varieties. Modern fruit breedings are also optimized for transport durability, but there might be potential for the usage of varieties which can be stored with a lower energy input.
Finally there are various sources available, which cover production values and quantities, acreage, regional distributions, workers, stocks and imports and exports (even for different product qualities, i.e. organic) for present supply chains [14][36][6][22]. For the past supply chains some data is available, including: production cost, trade and production quantities as well as imports and exports [34][34]. Creating new indicators, or comparing quantitative indicators between present and past supply chains will be difficult. The ecological dimension of past supply chains is hardly discussed in the reviewed literature, concepts for improvement can therefore only be developed on the qualitative comparison. Indicators, like the product carbon footprint, might be a good base for the comparation of different present supply chains (regional, stored fruit vs. imported, freshly harvested fruit).

5. Conclusion

This paper follows the aim of developing concepts for future fruit supply chains which are more sustainable. As many modern trends in the fruit supply (regionalization, diversification of products, low energy and material usage) could also be witnessed in past supply chains around the start of the 20th century. Therefore, a qualitative comparison between past and present supply chain has been conducted on the basis of a literature review. Identified needs and research gaps are the development of better sustainability indicators, a functional definition of regionality together with an analysis of realized transport distances and further discussion of how new innovations together with old methods and knowledge might be able to realize improvement potentials. New trends like autonomous vehicles or artificial intelligence were almost not discussed in the literature. Cheap sensors and connectivity would allow for an extensive data collection, varying harvesting times and shelf life, weather and consumer behaviours might bear potentials for operations research methods and better management of supply chains [7] as well as artificial intelligence.
For a measurement of the logistical or ecological performance literature review needs to be extended using more sustainability related search terms and integrating expert knowledge.
Other technological potentials remain unused, for example inland waterway transport, which was very common in past apple chains.
As there are potentials in different areas (i.e.: indicators, technology, fruit varieties), different experts along the supply chain and the different areas should be selected and interviewed, to identify, discuss and assess the different options for sustainability improvement.

Literature

[1] Institut für Ernährungswirtschaft und Markt (Hrsg.) (2004). Land- und Ernährungswirtschaft – Von der Vielfalt zum System. 1. Marktforum des Institutes für Ernährungswirtschaft und Markt.

[2] Volker Hart, Aikaterini Kavallari, Peter Michael Schmitz, Tobias C. Wronka (2007). Supply Chain Analysis of Fresh Fruit and Vegetables in Germany. Discussion Paper. Nr. 36, Giessen.

[3] Klinger, J. Agrarökologie im indischen Bundesstaat Sikkim – Vorbild für eine nachhaltige Bioökonomie? Working Paper Nr. 12 Bioeconomy & Inequalities. Friedrich-Schiller-Universität Jena, Jena.

[4] Stolper, O. (2015). Bestimmungsgründe von Veränderungen in der Wertschöpfungskette für Obst und Gemüse. Dissertation. Humboldt-Universität, Berlin.

[5] Zander, K., Beske, P. (2015). Relationship Quality in the German Supply Chain of Organic Apples. In: Aktuelle Forschung in der Gartenbauökonomie. Tagungsband zum 1. Symposium für Ökonomie im Gartenbau am 27. Nov. 2013 in der Paulinerkirche Göttingen. Dirksmeyer, W., Theuvsen, L. (Hrsg.). Johann-Heinrich-von-Thünen-Inst, Braunschweig.

[6] Zander, K. (2011). Erfolgsfaktoren in der Wertschöpfungskette für ökologische Äpfel.

[7] Leithner, M., Fikar, C. (2019). A simulation model to investigate impacts of facilitating quality data within organic fresh food supply chains. Ann Oper Res.

[8] Reiche, R., Fritz, M., Schiefer, G. (2009). Interaction models in the fresh fruit and vegetable supply chain using new technologies for sustainability and quality preservation.

[9] Rees, D. (2018). Frischelogistik bleibt 2018 schwierig. Fahrermangel verschärft sich – Dienstleister wollen Preiserhöhung – Nordfrost baut neues Netz für Kühltransporte auf. Lebensmittelzeitung **2018**/5, 45–46.

[10] Eikenbusch, M. (2018). Zur Implementierung von nachhaltigkeitsorientierten Managementsystemen in Obst- und Gemüsegenossenschaften. Dissertation. Universität Witten/Herdecke gGmbH, Witten/Herdecke.

[11] Stockinger, B. T., Duenbostl, C., Pöchtrager, S. „Nachhaltigkeitslabels“ bei Obst und Gemüse aus Sicht österreichischer KonsumentInnen. In: Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie, 211–220.

[12] Mempel, H., Hannus, T. (2016). Nachhaltigkeit in der Wertschöpfungskette Obst, Gemüse und Kartoffeln.

[13] Klein, A., Menrad, K., Gabriel, A., Zapilko, M. (2015). Klima-Kennzeichnung von Gartenbauprodukten? Ansichten und Anforderungen verschiedener Akteure und Stakeholder an ein C02-Zertifizierungs- und Labelling-System. In: Aktuelle Forschung in der Gartenbauökonomie. Tagungsband zum 1. Symposium für Ökonomie im Gartenbau am 27. Nov. 2013 in der Paulinerkirche Göttingen. Dirksmeyer, W., Theuvsen, L. (Hrsg.). Johann-Heinrich-von-Thünen-Inst, Braunschweig.

[14] Balster, A., Friedrich, H., Ottemöller, O., Rolko, K. (2016). Schlussbericht zum Teilprojekt Quantitative Modellierung der Lebensmittelversorgung in Deutschland des Verbundprojektes SEAK.

[15] Reuter, K. (2005). Marketing Chain Managmenet auf Ökomärkten in Mittel und Osteuropa.

[16] Sauter, A., Meyer, R. (2003). Potenziale zum Ausbau der regionalen Nahrungsmittelversorgung. Endbericht zum TA-Projekt “Entwicklungstendenzen von Nahrungsmittelangebot und -nachfrage und ihre Folgen”. TAB-Arbeitsbericht. Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag (TAB).

[17] Knickel, K., Schaer, B., Sprenger, B. (2003). Macro-level analysis of food supply chain dynamics and diversity: An overview for Germany.

[18] Schulte, M., Sonntag, W., Theuvsen, L. Der Markt für Obst und Gemüse. In: Die landwirtschaftlichen Märkte an der Jahreswende 2014/15, 49–61.

[19] Dirksmeyer, W., Garming, H., Fluck, K. (2012). Bewertung der nationalen Strategie für nachhaltige operationelle Programme im Obst- und Gemüsesektor in Deutschland. Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei.

[20] Bitsch, V. (2015). Herausforderungen nachhaltiger Wertschöpfungsketten im Gartenbau. In: Aktuelle Forschung in der Gartenbauökonomie. Tagungsband zum 1. Symposium für Ökonomie im Gartenbau am 27. Nov. 2013 in der Paulinerkirche Göttingen. Dirksmeyer, W., Theuvsen, L. (Hrsg.). Johann-Heinrich-von-Thünen-Inst, Braunschweig.

[21] Lohrberg, F. (2001). Stadtnahe Landwirtschaft in der Stadt- und Freiraumplanung. Ideengeschichte, Kategorisierung von Konzepten und Hinweise für die zukünftige Planung. Dissertation. Universität Stuttgart, Stuttgart.

[22] Wellner, M., Knoop, M., Theuvsen, L. Der Markt für Obst und Gemüse. In: German Journal of Agriculutral Economics, 82–96.

[23] Garming, H., Strohm, K., Dirksmeyer, W. (2015). Wirtschaftlichkeit der Apfelproduktion in Deutschland und Italien. In: Aktuelle

Forschung in der Gartenbauökonomie. Tagungsband zum 1. Symposium für Ökonomie im Gartenbau am 27. Nov. 2013 in

[24] Meißel, E. (2010). Analyse der Warenversorgung und Maßnahmen zur Verbesserung der Warenverfügbarkeit am Point of Sale in einem Lebensmitteleinzelhandelsunternehmen. Westsächsischen Hochschule Zwickau.

[25] Gotz, L., Njavro, M., Hanf, J. H., Pieniadz, A. (2009). Vertical coordination with growers in the supermarket fresh fruit and vegetables supply chain in Croatia. German Journal of Agricultural Economics **58**/08, 363–371.

[26] Andreas Hartwig (2018). Frischware profitiert von Künstlicher Intelligenz. Wachsende Sortimente und schnellere Liefergeschwindigkeiten erfordern die Optimierung der Logistikprozesse. Lebensmittelzeitung **2018**, 46.

[27] Zude, M., McRoberts, N. (2006). Prozessoptimierung in der Versorgungskette frischer Produkte - Die Basis sind zerstörungsfreie Inhaltsstoffanalysen. 204–205 Seiten / LANDTECHNIK, Bd. 61 Nr. 4 (2006)

[28] Ruiz-Garcia, L., rodriguez-bermejo, J., Robla, J., Barreiro, P. (2007). Review: Monitoring the intermodal, refrigerated transport of fruit using sensor networks. Spanish journal of agricultural research, ISSN 1695-971X, Nº. 2, 2007, pags. 142-156 **5**.

[29] Hoener zu Drewer, J. (2007). Analyse der Kühlkette im Handel und Integration von der Paulinerkirche Göttingen. Dirksmeyer, W., Theuvsen, L. (Hrsg.). Johann-Heinrich-von-Thünen-Inst, Braunschweig, 129–147. RFID-Technologie. Diplomarbeit, Universität Paderborn.

[30] Zude, M., Linke, M., Herold, B., Reisch, R., Ahlers, H. (2002). Qualitätsmonitoring im Fruchtcontainer. 218–219 Seiten / LANDTECHNIK, Bd. 57 Nr. 4 (2002) /

[31] Truppel, I., Siering, G., Zude, M., Herold, B. (2002). Telemetrie zur spektrometrischen Qualitätsbestimmung im Feld. 24–25 Seiten / LANDTECHNIK, Bd. 57 Nr. 1 (2002) /

[32] Alexander, F., Hipp, T., Scholze, T., Wagner, F., Schöler, T., Krupp, M. (2012). Das dynamische Mindesthaltbarkeitsdatum. Auf dem Weg zu einer Echtzeitereignisverarbeitung in der Lebensmittellogistik. Studienarbeit. Hochschule für Angewandte Wissenschaften Augsburg, Augsburg.

[33] Hofmann, J. A. (2014). Obstlandschaften 1500 - 1800. Historische Geographie des Konsums, Anbaus und Handels von Obst in der Frühen Neuzeit. University of Bamberg Press, Bamberg.

[34] Janson, A. (1917). Über die Obstversorgung Deutschlands im und nach dem Kriege. Weltwirtschaftliches Archiv **9**, 280–310.

[35] Bannier, H.-J. (2005). Genetische Verarmung beim Obst und Initiativen zur Erhaltung der genetischen Vielfalt. Samensurium **16/2005**, 61–68.

[36] Friedrich, N., Schaffarzyk, S., Theuvsen, L. Der Markt für Obst und Gemüse. In: German Journal of Agriculutral Economics, 85–95.

Lean Manufacturing, Industry 4.0 and Sustainability: future research directions

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Abstract

The current competitive environment of manufacturing is characterized by, among other things, increasing global competition, shorter product life cycles and increasing individualization of products. This puts pressure on the flexibility of manufacturing companies and on the efficiency of their resources to meet customer demand and stay competitive. To meet these challenges, companies are forced to continually innovate and improve their operations management strategies and processes. Lean Manufacturing has been the most prominent methodology for improving the operational performance in manufacturing companies for several decades. Similarly, Industry 4.0 is one of the most promising approaches to meet future challenges in the production environment. Different approaches are considered in the literature to analyze the link between these two domains. However, few studies investigate how these philosophies should be integrated to offer a streamlined and high-quality transformation process, and their respective influence on the three main pillars of sustainability: economic, environmental, and social. The purpose of this paper is to present a review and analysis of the literature on the relationship between these three management systems: Lean Manufacturing, Industry 4.0 and sustainability. In particular, analyze current proposals and simultaneously identify gaps in the existing literature and future research directions to develop a specific integrated model.

1. Introduction

Nowadays, Lean Manufacturing (LM), Industry (I4.0), and sustainability are important concerns for the companies and in a general way for the society, principally, the influence of the two production philosophies, LM and I4.0, in the three main pillars of sustainability: economic, environmental, and social.

LM has for more than two decades been the most prominent methodology for improving the operational performance in manufacturing companies. Originating from the Toyota Production System, LM is built on the idea of eliminating waste in all forms by focusing on the activities that create value for the customer. It is a low-tech continuous improvement approach that focuses on employee empowerment and the streamlining of manufacturing activities [6]. According to a survey released in 2007, almost 70% of American manufacturing plants have implemented some form of Lean Manufacturing project [20]. While, a survey from Germany reports that over 90% of the surveyed manufacturing companies claim to have initiated a Lean Manufacturing initiative [11].

However, given the increasing complexity of operations, many companies have found that LM by itself is not sufficient to address their operational challenges. Recently, a set of advanced digital technologies known as I4.0 has emerged to offer new approaches for dealing with complexity and improving productivity. By deploying the right combination of technologies, manufacturers can

boost speed, efficiency, and coordination and even facilitate self-managing factory operations.
All in all, I4.0 is seen as the future of manufacturing and is presented as a concept that manufacturers need to embrace to stay competitive.
Similarly, the concept of sustainability has received increasing global attention from the public, academic, and business sectors. The World Commission on Environment Development (WCED) defined sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
In spite of everyone knowing the three pillars of sustainability it is quite difficult to choose the criteria to characterize and evaluate the degree of sustainability of each organization.
The purpose of this paper is to analyze the relation between these three management systems: Lean Manufacturing, I4.0 and sustainability. In particular, analyze current proposals and simultaneously identify gaps in the existing literature and future research directions to develop a specific integrated model
The paper is structured in four sections. Following this introduction (Section 1), a brief review of the literature about LM, I4.0 and sustainability is given in Section 2. Section 3 defines according to the literature the influence of LM and I4.0 in each dimension of sustainability. The main research results and conclusions are then presented in Section 4.

2. Research background

2.1. Lean Manufacturing

The concept of lean became popular through Womack in 1990 with the book 'The Machine That Changed the World'. Lean production has been defined in many different ways. One reason for the lack of a coherent definition might be that the concept is still evolving [12]. However, the main goal of a lean system is to produce products or services of higher quality at the lowest cost and in the least time by eliminating wastes. In the lean context, waste is defined as anything other than the minimum amount of equipment, materials, parts, space and time which are absolutely essential to add value to the product.
Apart from a holistic management focus based on a number of objectives and principles, lean also encompasses a set of practices, tools, techniques and methodologies. However, there is no standard LM implementation framework, rather it is about various mature tools, such as 5S, six sigma, TPM, JIT, VSM, Kaizen, etc. [3, 18].
LM may be viewed as a configuration of practices/tools because the relationships among the elements of LM are neither explicit nor precise in terms of linearity or causality. A configuration approach helps to explain how a lean system is designed from the interaction of its constituent elements taken as a whole, as opposed to designing the system one element at a time. From a theoretical standpoint, lean management is seen as a tightly coupled system where the constituent elements hold together in mutual dependence. It is the self-reinforcing effects of this kind of mutual dependence that contribute to the superior performance associated with lean management on the one hand and make it rare, valuable and difficult to imitate by competitors on the other hand [21].
With the rise of environmental and social consciousness, the definition of lean has been expanded to incorporate concepts of economic, social, and environmental sustainability. The USA's Environmental Protection Agency [10] included among the aims of LM respect for the people and the environment.

2.2. Industry 4.0

In contrast with the three previous industrial revolutions, I4.0 is the first to be announced a priori. Although this provides an excellent opportunity to shape and optimize the solutions before they are fully released, the lack of empirical data makes the research highly theoretical, and there are plenty of disagreements and differences in the literature regarding what I4.0. [7]. This ambiguity in definitions makes it harder to align research in the area, as well as making it more complicated for practitioners to understand what I4.0 entails and how to achieve this transition. Consequently, the results of empirical testing will make only marginal contributions [21].
The I4.0 is associated with the technical perspective of a Cyber-Physical-System (CPS) integrated into manufacturing operations and with Internet of Things (IoT) technologies into the industrial processes, which can be represented by smart factories, smart products, and extended value networks – vertical, horizontal and end-to-end integration. People, machines, and resources are vertically linked, while companies are linked horizontally across the value chain as in a social network created by CPS.
It allows the flow of goods, services and data in a controlled way, through the value chain, with operations with a high degree of autonomy and high capacity to transmit useful information to decision- making.
This phenomenon will be the most powerful driver of innovation over the next few decades triggering the next wave of innovation [13]. Thus, the main features related to the I4.0 such as real-time capability, interoperability and the horizontal and vertical integration of production systems through

ICT systems, are regarded to be the response to current challenges that companies must face to stay competitive in terms of globalization and intensification of competitiveness, the volatility of market demands, shortened innovation and product life-cycles and the increasing complexity around products and processes [2].
This context provides opportunities to make manufacturing more responsive to user-driven design and to align it better with customer value creation processes and contexts [9]. From this approach, companies need to develop new capabilities, learn more about their customers (use digital capabilities to obtain customer information, promote evidence-based decision-making, develop comprehensive customer experiences, etc.) and become an ecosystem beyond individual value chains (become a great builder of partnerships with new interest groups).

2.3. Sustainable manufacturing

Sustainable Manufacturing can be defined as the integration of processes and systems capable to produce high quality products and services using less and more sustainable resources (energy and materials), being safer for employees, customers and communities surrounding, and being able to mitigate environmental and social impacts throughout its whole life cycle. Benefits of sustainable manufacturing include cost reduction through resource efficiency and regulatory compliance improvement, better brand reputation, new market access, less labor turnover by creating attractive workplaces, and long-term business approach by creating opportunities to access financing and capital [5,10].
The authors [5] define the sustainable manufacturing scope in four areas with its respective objects and applied disciplines:

- Manufacturing technologies (how things are manufactured) with focus on process and equipment (machine-tool, facility);
- Product life cycles (what is to be produced) with focus on product and services' design;
- Value creation networks (organisational context) with focus on organisations of companies and manufacturing networks;
- Global manufacturing impacts (transition mechanisms towards sustainable manufacturing) with focus on studies about manufacturing impacts on the world, including society, environment, and economy.

Different aspects can contribute to a positive sustainable manufacturing strategy implementation, among others, the development of sustainability indicators, policies and procedures, company's cultures and internal conditions for sustainability, sustainable design strategies, and stakeholders' engagement for sustainability and technologies [4].

3. Influence of Lean Manufacturing and Industry 4.0 in the dimension of sustainability

3.1. Lean Manufacturing and Sustainability

This section discusses the relations between LM and the three dimension of sustainability. Companies that have adopted LM to improve their results also want to be seen as socially responsible. Sustainability is considered the new LM frontier [17]. Productivity and cost-saving are necessary for the economic survival of organizations. However, these tasks should be achieved in a sustainable way, by mitigating negative environmental and social impacts and contributing to a sustainable society [19].
A review of literature carried out in the paper [22] shows preceding studies and examples of initiatives about the relationship between LM and the different dimensions of sustainability. In Table 1, a resume about some main contributions regarding the relation or influence of LM in the three dimensions of sustainability are presented.

Table 1: Influence of Lean Manufacturing in the dimension of sustainability

Dimension	**Influence**
Economic	Increase profits
	Increase turnover
	Increase market share of the products
	Decrease operational costs
	Increase process performance
Environmental	Decrease industrial waste
	Increase the practice of circular economy
	Increase the collaboration with partners that follow good environmental practices
Social	Increase the participation of its employees in decision-making
	Increase the quality of work conditions
	Decrease working accidents

The author [1] indicates that when considered as a whole, lean positively impacts business performance on an aggregate level, as well as market performance individually. However, these effects are highly variable. This high variability therefore offers great opportunities for further research into the potential moderating variables that may affect these relationships.

The authors [15] establish a link between lean and green showing that adopters of Lean Manufacturing principles are more likely to also adopt ISO 14000 environmental standards. Results show, as expected, that the main impact of lean is related to an increase in the productivity and efficiency of manufacturing processes. It also identifies a very positive relationship between lean implementation and employee satisfaction and it positive impact on the company financial strength. These two aspects together indicate that implementation of lean methodologies can lead to an increased sustainability of the company.

3.2. Industry 4.0 and Sustainability

I4.0 has changed the way businesses and production are conducted in their entirety, in terms of procedures, methods, and practicability. The cost of I4.0 infrastructure seems to be reasonable when budgeted environmentally, but it is still difficult to predict its direct impact on sustainability.

The Table 2 show main recent contributions that have emerged for researchers on I4.0 and sustainability, underlying main dimensions considered are summarized.

Table 2: Influence of Industry 4.0 in the dimension of sustainability

Dimension	**Influence**
Economic	Increase: profits, value creation, efficiency, flexibility
	Increase turnover, and create new business models
	Decrease operational costs
	Improve processes performance, increase renewable resources, and improve circular economy
	High revenue through vertical and horizontal integration
Environmental	Decrease industrial waste
	Decrease energy intake of non-renewal energy sources
	Increase production of renewal energy
	Practice of circular economy
	Increase collaboration with partners that follow good environmental practices
Social	Corporate social responsibility is undertaken by companies towards consumers
	Customization and digitization
	Increase number of employees
	Improve conditions of the surrounding society
	Decrease working accidents
	Increase participation of employees in decision-making

Therefore, I4.0 provides new features and possibilities in manufacturing in two main aspects: the value added to the final customer and production process capabilities

According to the reference [8], environmental sustainability is positively impacted by I4.0 through comprehensive digitization that provides more accurate, high-quality management and real-time event management for the external environment. However, an explanation should be given here. It should be noted that sustainability is a broad concept; therefore, flows chosen to address environmental sustainability have already been used elsewhere. When an event is implemented, calculations of flow patterns will become simpler. Nonetheless, the positive effect of activities on the flows is highly dependent on the production quantity. When production increases, flows will also increase and there will be a transformation of negative impacts into positive trends by adopting an e-commerce environmental sustainability dimension.

Therefore, a gap still exists on how to integrate the efficient use of scarce resources, raw materials, information, responsible consumption, and energy with sustainable development goals in long-term solutions. To reduce pollution in the environment and achieve sustainability, the 4Rs—reduce, reuse, recycle, and replace—can be used. Hence, efficiency and eco-innovation will be realized in I4.0 and the sustainability.

'The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency'. – Bill Gates (cited in [16]). This quote illustrates why lean thinking is still important in an increasingly automated and digitalized world. It highlights the inevitable fact that an inefficient process that is automated is still inefficient and is basically automating some type of waste. The cost of automating an inefficient process also tends to be higher [13].

However, several of these studies only discuss and hypothesize on a conceptual level, while some of the empirical studies collect their data from secondary sources. To motivate an I4.0 and Lean Manufacturing integration, it is necessary to further investigate the potential performance implications through empirical studies. Although the current sample of studies gives some indications on the potential performance impacts, the studies are clearly insufficient in both width and depth. Central research issues in the future will be to measure what a successful I4.0 and Lean Manufacturing integration entails, as well as comparing the sustainability impacts with those of a 'pure' I4.0 or Lean Manufacturing system.

4. Conceptual model

The main point of interest for this article is to analyze the link between I4.0 and LM, as well as examine its implications on sustainability and the external factors influencing these relationships.

Therefore, the last step is to develop a conceptual model that explains the main constructs and the relationships between them.
The proposed model (Figure 1) illustrates the different theoretical lenses regarding these relationships and establishes a structure for summarizing the findings from the literature presented in section 3.

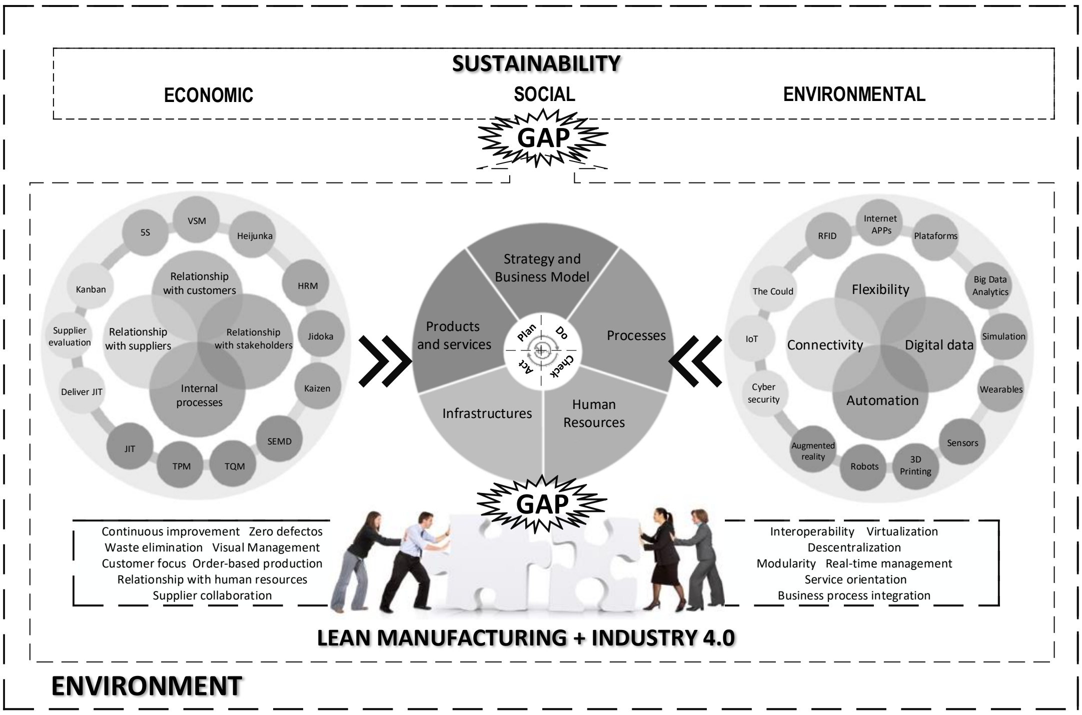

Figure 1: Conceptual model illustrating the relationships between I4.0, LM and sustainability

The conceptual model, in its graphic presentation, considers the environment as a moderating entity in the potential to integrate LM and I4.0, as well as the impact resulting from such integration on sustainability. The success of the execution of any management practice is closely related to the socio-economic context where it is developed (country, business sector, supply chain) that can influence to a greater or lesser degree, in a differentiated way, on each company analyzed.
The central segment of the model shows one of the currently unsolved problems in the literature, how to apply LM and I4.0 in an integrated way. This integration should allow technology enablers to further support and develop LM practices and in turn these exert facilitating effects on the implementation of I4.0. This integration starts from instituting in the organization the pillars of both work philosophies, generating new business models on their bases.
As the central core of the conceptual model, five strategic points are represented to analyze to evaluate, implement and maintain a transformation project: strategy and business model, processes, organization and human resources, infrastructures, products and services.

The two influencing circles on the central core represent lean practices (left) and I4.0 technology enablers (right). Both have been represented in an interrelated way because the implementation of an LM practice or a technological enabler (I4.0) is not simply the sum of the results of each of them. Rather, they complement and work synergistically to create a streamlined, high-quality system that increases business profits. This helps explain how a lean system is designed from the interaction of its constituent elements taken as a whole, rather than designing the system one element at a time. The self-reinforcing effects of this type of mutual dependence are those that contribute to a higher associated sustainability.
At the center of the model and inscribed in the central nucleus, the dynamo of the future research, composed in this case by the permanent interrelation between lean production models and IT. Its internal logic of execution, this interaction must occur in an environment of continuous improvement, supported by the four stages of the so-called Deming cycle (Plan-Do-Check-Act).
The model also represents an existing GAP in the preceding studies: how to measure the impact of the changes imposed on the production system by

the integration of LM and I4.0 on operational performance and on the different dimensions of sustainability (economic, social and environmental)?

5. Conclusions

In conclusion, after reviewing all these studies, the challenges and opportunities associated with the implementation of I4.0 are still uncertain, and the technologies associated with this industry in terms of sustainability have not been adequately explored because these are still new technologies. The literature findings are classified into four research streams: (1) I4.0 supports LM, (2) LM supports I4.0, (3) implications of an I4.0 and LM integration in the sustainability, and (4) the effect of environmental factors on an I4.0 and LM integration. It is clear from the findings that this area is still immature, with seemingly no common platform of knowledge to build the research on. The conceptual model, in its graphic presentation, considers the environment as a moderating entity in the potential to integrate LM and I4.0, as well as the impact resulting from such integration on sustainability. This proposal illustrates the different theoretical lenses regarding these relationships and establishes a structure for summarizing the findings from the literature.

References

[1] Abreu, R; Darkys E.; Luján, D.; Garrido, P.; Escobar, B. (2018): A meta-analytic study of the impact of Lean Production on business performance. International Journal of Production Economics. 200: 83-102.

[2] Arnold, D; Kiel, K. (2017): Innovative Business Models for the Industrial Internet of Things, BHM Berg- und Hüttenmännische Monatshefte, 169: 371-381.

[3] Bhamu, J.; Singh, K. (2014): Lean Manufacturing: literature review and research issues. Int. J. Oper. Prod. Manag. 34: 876–940.

[4] Bogle, I. (2017): A perspective on smart process manufacturing research challenges for process systems engineers. Engineering 3:161-165.

[5] Bonvoisin, J; Stark, R.G; Seliger, G. (2017): Field of research in sustainable manufacturing. In book: Sustainable Manufacturing. 3-20.

[6] Buer S. (2020): Investigating the Relationship between Lean Manufacturing and Industry 4.0. Doctoral theses at Norwegian University of Science and Technology NTNU, 2020:65.

[7] Buer S.; Strandhagen J.; Chan F. (2018): The link between Industry 4.0 and Lean Manufacturing: mapping current research and establishing a research agenda, International J of Prod Res, 56: 2924-2940.

[8] Burrit, L.R; Christ, K. (2016): Industry 4.0 and environmental accounting: a new revolution? Asian Journal of sustainability and social responsibility 1: 2-16.

[9] Ehret, J. (2017): Unlocking value from machines: business models and the industrial internet of things. Journal of Marketing Management. 33: 111-130.

[10] EPA. (2018): "Sustainable Manufacturing" hhttps://www.epa.gov/sustainability/sustainable-manufacturing.

[11] Glass, R; Seifermann, S; Metternich, J. (2016): The Spread of Lean Production in the Assambly, Process and Machining Industry. 5th CIRP Global Web Conference Research and Innovation for Future Production. Germany. Procedia CIRP 55, 278-283, 2016.

[12] Hine, P; Holweg, M; Rich, N. (2004): Learning to evolve. A review of contemporary lean thinking. International Journal of Operations & Management 24: 994-1011.

[13] Kaggermann H. (2015): Change Through Digitazation-Value creation in the Age of the Industry 4.0. Management of Permanent Change, 23-45.

[14] Kaspar, S. (2015): Lean und Industrie 4.0 in der Intralogistik: Effizienzsteigerung Durch Kombination der Beiden Ansätze Productivity Management 20 (5): 17–20.

[15] King, A.A; Lenox, M.J. (2001): Lean and Green? An empirical examination of the relationship between Lean Production and Environmental Performance. Production and Operation Management. 10, 244-256.

[16] Krishnan, K. (2013): Data Warehousing in the Age of Big Data. Burlington.

[17] Martínez-Jurado, P.; Moyano-Fuentes, J. (2014): Lean management, supply chain management and sustainability: A literature review. J Clean. Prod. 85, 134–150.

[18] Moyano, J.; Sacristían, M.; (2012): Learning on lean: a review of thinking and research. Int. J. Oper. Prod. Manag. 32:551–582.

[19] Pampanelli, A.B.; Found, P.; Bernardes, A.M. (2014): A lean & green model for a production cell. J. Clean. Prod., 85:19–35.

[20] Pay, R. (2018) Everybody`s jumping on the lean bandwagon but many are being taken for a ride. Industry week 503 (780).

[21] Shah, R.; Ward, P. (2007); Defining and developing measures of lean production. J. Oper. Manag. 25: 785–805.

[22] Varela, L; Araújo, A; Ávila, P; Castro, H; Putnik, G. (2019): Evaluation of the relation between Lean Manufacturing, Industry 4.0, and Sustainability. Journal Sustainability 11:2-19.

Logistics operations after major disasters

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Abstract
In recent years, the world has been stricken by several natural or man-made disasters. Usually, when such events happen in an urban area, the consequences are very relevant and require an effort to recover their effects over the affected areas. The debris area concern and cleaning operations are very relevant to inhabitants to return to a normal life. In this study, the integrated scheduling vehicle routing problem to clean debris (SRP-CD) after major disasters is investigated. SRP-CD logistics includes strategical and operational decisions and, it is motivated by the complexity of the operations. The problem aims at loading, transporting and unloading debris during working days by synchronizing work-troops and dump trucks. The goal is twofold: minimizing the total time in number of working days, to perform the operations for cleaning the overall area, in the strategical level; and minimizing the total costs of vehicle routes in the operational one. In order to tackle the problem, constructive heuristics and Simulated Annealing are proposed. Numerical experiments were carried out, to check the performance and robustness of the proposed methods. Results showed that the methods are able to find good quality solutions within a reasonable running time.

1. Introduction
In recent years, the world has been stricken by several natural major disasters or man-made disasters. According to recent surveys, 55% of the world population lives in urban areas, which represents about 4.2 billion people [18]. When such disasters hit inhabited regions, they strongly impact population (causing displacement, homelessness and fatalities), environment (causing desertification) and urban infrastructures (causing massive damage to buildings and crops), involving huge costs of humanitarian aid and reconstruction [10]. The accumulation of debris caused in urban regions after major disasters becomes a concern. A great effort is required to perform cleaning operations due to the amount of debris. In addition, the removal planning can be very complex when an unexpected and large urban area is affected. However, these operations are very relevant to inhabitants to recover from their effects.

In this study, the integrated scheduling vehicle routing problem to clean debris (SRP-CD) after major disasters is investigated. SRP-CD logistics includes strategical and operational decisions and, it is motivated by the complexity of the cleaning operations, which can take months or even years to be concluded after a catastrophic event.

Let a work-troop be a team composed of excavators, bulldozers and human resources. The transportation network is modeled by a graph G = (V, E), where V is the set of vertices (crossroads) and E is the set of edges (routes). Given a set of work-troops (WTs) and a fleet of homogeneous vehicles, the problem aims at loading, transporting and unloading debris during working days, by synchronizing work-troops and dump trucks. The goal is twofold: minimizing the total time in number of working days to perform the operations for cleaning the overall area, and minimizing the total costs of vehicle routes. One may note that the strategical part of the problem concerns the scheduling of cleaning the debris points in a time horizon and the operational level covers the operations performed by the fleet of vehicles every day.

The SRP-CD involves the integration of classical optimization problems: a close related problem of the Resource-Constrained Project Scheduling Problem (RCPSP) [5, 11, 14] and, the Full Truckload Vehicle Routing Problem (FTVRP) [9]. The problems mentioned above are NP-Hard problems [2, 4]. Thus, the SRP-CD is NP-Hard.

The integration of optimization problems from different levels (tactical, strategical and operational) has received some attention in the last years [7, 8]. It is a challenging field since the global complexity of the integration can increase according to the complexity of each single problem. But, as shown in [15], the gains of addressing a problem in an integrated way is about 15%. Furthermore, in practical terms, integrated problems allow working with more realistic scenarios by including relevant constraints involved in a real application, as it is the case in SRP-CD, where the synchronization between the assigned WTs and dump trucks are considered. In this study, constructive heuristics and a *Simulated Annealing* (SA) metaheuristic are proposed. In addition, interesting instances for SRP-CD are described. To the best of our knowledge, these are the first contributions in the literature for SRP-CD, including all parameters mentioned above and the integration of two levels of optimization.

The remaining of this document is organized as follows. In Section 2, closely related studies from the literature are reviewed. In the following, the proposed methods are detailed in Section 3. Numerical results are described in Section 4, followed by conclusions and perspectives in Section 5.

2. Related works

The two classical optimization problems related to the SRP-CD are the RCPSP and the FTVRP. The former is defined as a project containing a set of tasks which must be concluded without interruption after starting [5, 11, 14]. Each task has resources requirements to be performed, a duration, and some of them may have predecessors. Objectives like minimizing the completion time or the make span are usually used. The models look for finishing all tasks of the project such that the constraints related to resources and predecessors are satisfied. Others descriptions of RCPSP can also include objectives of minimizing the total throughput time for all tasks or minimizing the total lateness for all tasks [14]. Compared to SRP-CD, the tasks in RCPSP could be seen as the debris nodes to be cleaned by the set of WTs and dump trucks. The resources could be seen as the set of WTs together with dump trucks. Some differences exist between RCPSP and SRP-CD such as the integration with VRP in SRP-CD, and the fact that SRP-CD is modeled in a graph due to the road network.

The second problem involved in the SRP-CD is the FTVRP [9]. FTVRP is defined as follows. Given a set of vehicles, the problem consists in defining routes containing trips where, on each trip, identical vehicles travel and transport a full load from an origin to a destination. Routes start and end at the depot and they do not exceed a predefined time limit. The objective is to minimize the total distance travelled, such that the vehicle capacity constraint is satisfied. The differences between SRP-CD and FTVRP are: (1) vehicles can only visit debris nodes with WTs assigned; (2) the pairs of load and unload points are not predefined as in the FTVRP. In SRP-CD, the optimization models/methods decide both which load point is serviced in a time period, and where the corresponding debris will be unloaded; (3) the operations of load and unload have times to be performed which affect the routes; and (4) the objective in SRP-CD aims to perform all the cleaning operations the fastest as possible, while minimizing the total travel time for the trucks.

Concerning the integration of NP-hard optimization problems, the study [8] surveys some real logistics applications. Another example can be found in [7], where an inventory routing problem is addressed. For this purpose, the management inventory is integrated to products' distribution in a time horizon. A location-routing problem is handled in [14]. The problem consists in locating additional depots and servicing customers from these depots. In [6], a scheduling of road network interruptions is integrated to a network design problem which focuses on the road network strong connectivity (i.e., there is a path between all pairs of nodes in the transportation network). One may note that the integration of problems in the literature has been focused on different optimization levels: strategical, tactical and operational. In terms of disaster relief, some related applications deal with cleaning road network problems. For instance, the problem to unblock roads [1], where the goal is to reconnect the network affected in the response phase to minimize the operation time. The vehicles (WTs) can clean the road by removing debris or by pushing debris to sides. A MILP formulation, a matheuristic based on a relaxation of the model, and a local search algorithm were proposed, the matheuristic is a method that solves, in an exact manner, a subproblem or part of the problem. Tests were done over data based on Istanbul road network and randomly generated data with Euclidean distances. The road emergency rehabilitation problem found in [16] focused two problems: the Road Network Accessibility Problem (RNAP), where the goal is to find paths for relief teams to reach the population as fast as possible; and the Work-troops Scheduling Problem (WSP), where the goal is to create a repairing schedule to improve access to refugee areas. As a consequence, improving the distribution of humanitarian aid for such areas. The WSP integrates a scheduling problem to a network design one. The authors proposed a mathematical model and three heuristics (a savings, a ranking and a lexicographical one) to solve large-scale realistic instance of Haiti earthquake in 2010. It contains 16,660 vertices and 19,866 routes for the urban network, and more than 500 blocked roads. An extension of this work is found in [3], where the authors proposed a dedicated local search for the WSP and two metaheuristics: a Greedy Randomized Adaptive Search Procedure (GRASP) and an Iterated Local Search (ILS). The methods were executed in theoretical instances and on a realistic instance aforementioned. These problems mainly differ from SRP-CD since they integrate scheduling to network design issues. In SRP-CD, a scheduling problem to routing decisions for debris transportation are coupled.

A closely related application to SRP-CD is found in a biomass supply chain [17]. The problem couples a Full Truckload Pickup and Delivery Problem (FTPDP) with a multiple vehicle synchronization. Three types of vehicles are used (trucks, loaders and lorries) to perform the material transportation from pickup nodes to delivery ones within a planning horizon of a single working day. A mathematical model and a matheuristic using a fix-and-optimize algorithm with a variable neighborhood decomposition search are proposed. Although this application contains several close related issues with the operational decisions of SRP-CD, one may note that it does not consider the strategical decisions integrated to the operational ones. To the best of our knowledge, the problem addressed in this study has not been addressed in the literature including all the aspects focused here.

3. Heuristic methods

The proposed heuristics are detailed in the following. First, multi-criteria constructive heuristics are presented in section 3.1. Then, a *SA* metaheuristic is described in section 3.2.

3.1. Constructive heuristics

The proposed constructive heuristics are able to generate initial feasible solutions for SRP-CD. The heuristics are composed of four main steps which are repeated throughout the solution construction: (a) the assignment of WTs to debris nodes, (b) the routing of dump trucks to debris nodes already with WTs, (c) the loading of dump trucks at the debris nodes and (d) the unloading of dump trucks at the landfills. The step (a) focuses on the strategical decisions of the WTs scheduling, while the steps (b), (c) and (d) are related to operational decisions of dump trucks' trips.

The heuristics perform a greedy or a random construction in the steps (a) and (b), according to a given criterion (cWT) to assign WTs to debris, and a criterion (cK) to route dump trucks. The step (c) performs load at dump trucks in each node, and in the step (d), full-loaded dump trucks are routed to the nearest landfill from the corresponding debris node. An overview of the constructive heuristic is presented in the Algorithm 1.

Algorithm 1: Constructive heuristics structure

```
Data: G = (V, E), cWT, cK
Result: s
s ← ∅
D' ← D
while D' = ∅ do
    assignmentWT (s, cWT, D')
    routingDumpTrucks (s, cK, D', G)
    load (s, D')
    unload (s, L)
return s
```

Six greedy criteria are proposed for the strategical decisions (i.e., assignment of WTs) and seven criteria are proposed for the operational decisions (i.e., routing dump trucks), resulting in 42 possible combinations of criteria to produce a complete feasible solution for SRP-CD. The former six criteria are as follows:

- Less Debris First (LDF): WTs are assigned to nodes with less amount of debris to collect. This is done in increasing order until all WTs are allocated.
- More Debris First (MDF): WTs are allocated in decreasing order of the higher amount of debris.
- Smaller Travel Time First (STTF): WTs are set to the nearest nodes from the depot, in terms of travel time, according to an ascending order.
- Greater Travel Time First (GTTF): WTs are allocated to most distant debris nodes from the depot, in terms of travel time. This is performed in decreasing order using this criterion.
- Smaller Ratio (Debris/Travel Time) First (SDTTF): a ratio between the amount of debris and the travel time is done, and then WTs are assigned in increasing order of debris nodes with the smaller ratio.
- Greater Ratio (Debris/Travel Time) First (GDTTF): a ratio between the amount of debris and the travel time is done, and then WTs are allocated in decreasing order of debris nodes with the greatest ratio.

The greedy criteria *LDF*, *MDF*, *STTF*, *GTTF*, *SDTTF* and *GDTTF* are also adapted for the operational level of decision and assigning dump trucks accordingly instead of WTs. In addition, the *Less Trucks First* (LTF) criterion is also used and consists in routing dump trucks to debris nodes with less trucks already allocated. This is done in increasing order of the dump trucks number, working in a debris node. One may note that the constructive heuristics using the aforementioned criteria are deterministic, i.e., they produce only one feasible solution each.

In addition, a greedy approach called, *Greedy Constructive Heuristic* (GCH), returns the best solution found among the 42 possible runs of the Algorithm 1 using the criteria for WTs and dump-trucks. A random approach, referred to as *Random Constructive Heuristic* (RCH), builds a feasible solution using a random choice to assign WTs to debris nodes, as well as a random choice to allocate dump trucks to debris nodes. The algorithm slight differs from the one of *GCH*. In the *RCH*, several executions of the Algorithm 1 are done until a stop-criterion is reached.

3.2. Simulated Annealing

The *Simulated Annealing* (SA) is a metaheuristic inspired by the process of physical annealing with crystalline solids, where after heating, the solid is slowly cooled to reduce their effects over the material, achieving a solid with a superior structural integrity [12].
As described by the authors in [12], the *SA* moves to the solution in the search space starting with an initial temperature and performing several iterations controlled by a cooling rate. As the temperature cools, improving solutions are always accepted, however, inferior solutions are accepted with a probability based on the current temperature. This is done to try to escape from local optima.

Algorithm 2: Simulated annealing metaheuristic

```
Data: G = (V, E), cWT, cK, T0
Result: s
1    T ← T0, k ← 0.998
2    s'← ConstructiveHeuristic (G, cWT, cK)
3    s ← s''
4    while stop-criterion not met do
5        s'' ← Move (s', cK)
6        ΔF ← (F(s'') − F(s'))
7        if (F(s'') < F(s)) then
8            s ← s''
9        if (ΔF < 0) then
10           s' ← s''
11       else
12           if (rnd(0, 1) < e^(−ΔF/T)) then
13               s' ← s''
14       T ← kT
15   return s
```

A general *SA* scheme is given in Algorithm 2. Parameters are initialized in line 1 (resp. the temperature and the cooling rate). Then, a feasible initial solution is generated in line 2. In line 3, the incumbent solution is attributed to the final solution. The basic idea is to start with an initial solution and an initial temperature T = T0. While the stop-criterion is not reached, at each iteration, a local search *Move()* is done at the incumbent solution to generate a neighbor solution s'' in line 5. Since F(s) represents an objective value for a generic solution s, in line 7, the best solution found is kept in s. In line 9, if the neighbor solution is better than the incumbent solution, the latter is updated. Otherwise, a probability of accepting a worse neighbor solution is employed in line 12 (hill-climbing move of the method [12]). In line 14, the temperature T is cooled by the cooling rate k. The best solution found is returned in line 15.
The *SA* proposed for the SRP-CD is as follows. The initial solution applies a greedy constructive heuristic described in Section 3.1. The Move() function applies a random local search, it makes use of a removal procedure that takes away a random debris node of the scheduling from some work-troop (WT) in the current solution. It is worth mentioning that removing a debris node implies that the vehicles' routing are also removed. Next, the removed debris is inserted in a random position in the scheduling of some WT and after the insertion, the routing is done again using the greedy approach and the criterion cK. For the stop-criterion, the authors in [13] defined a threshold (ϵ) for the temperature close to zero, thus, the temperature T is cooled until a value $\epsilon = 10^{-6}$.

4. Preliminary results

For preliminary results, the tests were performed on a cluster virtual machine with Intel Xeon Processor (Skylake) CPU @2.00GHz, 25GB of RAM and 5GB of swap, using the operational system Ubuntu 18.04.1 LTS. All the cores and RAM were used.
In order to perform the tests, two groups of instances (G1 and G2), with 24 instances each, were created from small- to medium-size instances with a random distribution of debris over a cartesian plane. Each instance was named with its main characteristics, for example, a name *T55.W2.K2.D30.L2* represents an instance with a working day of 55 time units, 2 WTs, 2 dump trucks, 30 debris nodes and 2 landfills. The benchmarks of instances G1 and G2 were used to measure robustness and scalability of the proposed heuristics.

The results of the 42 different combinations for the greedy constructive heuristics were compared by ranking analysis, i.e., absolute rank (Abs-Rank) and the average rank (Avg-Rank), which are as follows:

- The Abs-Rank gives the value 1 for each heuristic that found, for a given instance, the best solution value of the scheduling (F1) and the routing (F2) among all the others heuristics. In case of two or more heuristics finding the same best solution value, both will be rewarded. The sum of all rankings for all instances provides how many times a heuristic found the best solution value among all the others for a group of instances.

- The Avg-Rank defines a classification for the heuristics, i.e., the heuristic which finds the best solution value among all the others receives the rank number 1; the heuristic which finds the second best solution value receives the rank number 2 and so on. If two heuristics find the similar solution value, then both will receive the average of the corresponding individual ranks. The average of all Avg-Rank for every heuristic, considering all instances, indicates the average classification of a heuristic among all the others for a group of instances.

For group G1 of instances, the best Abs-Rank was found using the combination of MDF for the scheduling and GDTTF for the routing; For group G2 of instances, the best Abs-Rank and Avg-Rank was found using the combination of LDF for the scheduling and STTF for the routing.

4.1. Heuristics comparison

Comparison results for the *GCH*, *RCH* and *SA* are presented in Table 1 for both groups. For *GCH*, the best solution found between the 42 combinations was chosen. For the *RCH*, a fixed execution time of 20 seconds was chosen as stop-criterion. For the *SA*, it was chosen to use the best ranked greedy solution from the ranking analysis in each group as initial solution. The methods *RCH* and *SA* had 10 runs for each instance and the results considered the best solution found among the 10 runs.
For each method, the results show the number of best known solutions found among the methods (#B.K.); the average difference in working days to the B.K. (Avg. F1), the average deviation in the routing for the B.K. (Avg. F2), and the average running time in seconds (Avg. Time(s)). The line Avg. (Total) represents all instances for each group. The number of WTs and trucks are *(2, 2), (2, 3), (3, 3)* and *(3, 4)* in each line for G1. For G2, the numbers are *(2, 2), (3, 3), (4, 4), (2, 4), (3, 6)* and *(4, 8)*. According to the results, for the group G1, the method *RCH* found the best known solutions in all instances (bold in table). The *GCH* solutions have on average 0.21 more working days with a routing 1.76% worse than the best known solutions. For the *SA*, the solutions require on average 1.00 more working day with a routing 3.27% worse than the best known solutions. A different behavior was found for the instances in G2. The best known solutions were found by the *SA*. The *RCH* solutions have on average 2.96 more working days with a routing 7.27% worse than the best known solutions. The worst method was the *GCH*, where the solutions have on average 4.21 more working days with a routing 10.45% worse than the best known solutions. Considering the running time, the fastest method was the *GCH* followed by the *RCH* and last, the *SA*. Thus, the results showed that the *SA* was able to improve the initial solutions for the larger instances in spite of the running time.

Table 1: Deviation of all methods against the best known solutions for the groups G1 and G2.

Instance	GCH				RCH				SA			
	#B.K.	Avg.			#B.K.	Avg.			#B.K.	Avg.		
		F1	F2	Time (s)		F1	F2	Time (s)		F1	F2	Time (s)
T28.W*.K*.D5.L1	0	0.00	0.54%	0	4	0.00	0.00%	20	0	1.75	1.44%	131
T29.W*.K*.D5.L1	0	0.50	1.72%	0	4	0.00	0.00%	20	0	0.50	3.07%	141
T30.W*.K*.D5.L1	0	0.00	1.56%	0	4	0.00	0.00%	20	0	0.75	3.05%	126
T35.W*.K*.D5.L1	0	0.25	2.67%	0	4	0.00	0.00%	20	0	1.00	4.59%	124
T40.W*.K*.D5.L1	0	0.00	1.84%	0	4	0.00	0.00%	20	0	0.75	4.07%	122
T40.W*.K*.D6.L1	0	0.50	2.21%	0	4	0.00	0.00%	20	0	1.25	3.39%	140
Avg. (Total)	(0)	0.21	1.76%	0	**(24)**	**0.00**	**0.00%**	20	(0)	1.00	3.27%	131
T40.W*.K*.D15.L2	0	2.00	10.64%	0	0	1.17	5.94%	20	6	0.00	0.00%	330
T40.W*.K*.D20.L2	0	3.33	10.42%	0	0	2.00	6.44%	20	6	0.00	0.00%	467
T55.W*.K*.D30.L2	0	4.83	12.52%	0	0	3.67	10.35%	20	6	0.00	0.00%	637
T60.W*.K*.D40.L2	0	6.67	8.23%	0	0	5.00	6.37%	20	6	0.00	0.00%	950
Avg. (Total)	(0)	4.21	10.45%	0	(0)	2.96	7.27%	20	**(24)**	**0.00**	**0.00%**	596

Regarding the meaning of these results in terms of a real application, it can be considered, for example, the instance *T60.W2.K2.D40.L2* containing 2 WTs, 2 dump trucks, 40 debris sites and 2 landfills. Supposing a cost associated with each traveled minute for a dump truck and a working day of 8 hours in the real case, each time unit from the instance would represent 8 minutes. The best result for this instance was produced by the *SA*, with 77 days for cleaning and a total travel time of 7939 time units or 63512 minutes for both dump trucks. For this example, the result found by *RCH* has 89 days and 8496 time units, i.e., 12 days and 557 time units more than the best solution. For the *GCH*, the result presented 91 days and 8611 time units, i.e., 14 days and 672 time units more than the best solution. Thus, in addition to the reduced time in the working days for cleaning, the *SA* solution presented an improvement of 7.02% and 8.46% for the cost compared to the *RCH* and the *GCH* respectively.

5. Conclusions and perspectives

The developments for the integrated Scheduling vehicle Routing Problem to clean debris (SRP-CD) in an urban area after major disasters were presented. Instances from small- to medium-sizes were generated and tested. In order to address the problem, a set of constructive heuristics based on greedy (*GCH*) and random (*RCH*) criteria and a SA metaheuristic were proposed.
The results showed that the proposed methods are able to find good quality solutions within a reasonable running time. The *RCH* found the better results among the methods for G1. The *SA* produces the better results among the methods for G2, showing the impact of the *SA* in improving solutions for bigger instances. As future approaches, it can be proposed the application of the methods in a real case study, or in different scenarios with clustered distributions. In addition, different metaheuristics like Adaptive Large Neighborhood Search can be proposed.

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References

[1] Akbari, V. and Salman, F. S. (2017). Multi-vehicle synchronized arc routing problem to restore post-disaster network connectivity. European Journal of Operational Research, 257(2):625–640.

[2] Archetti, C., Feillet, D., Gendreau, M., and Speranza, M. G. (2011). Complexity of the vrp and sdvrp. Transportation Research Part C: Emerging Technologies, 19(5):741–750.

[3] Barbalho, T. J., Santos, A. C., and Aloise, D. J. (2020). Metaheuristics for the work-troops scheduling problem. International Transactions in Operational Research, In press.

[4] Blazewicz, J., Lenstra, J. K., and Kan, A. R. (1983). Scheduling subject to resource constraints: classification and complexity. Discrete applied mathematics, 5(1):11–24.

[5] Brucker, P., Drexl, A., Möhring, R., Neumann, K., and Pesch, E. (1999). Resource-constrained project scheduling: Notation, classification, models, and methods. European journal of operational research, 112(1):3–41.

[6] Coco, A. A., Duhamel, C., and Santos, A. C. (2020). Modeling and solving the multi-period disruptions scheduling problem on urban networks. Annals of Operations Research, 285(1-2):427–443.

[7] Coelho, L. C., Cordeau, J.-F., and Laporte, G. (2014). Thirty years of inventory routing. Transportation Science, 48(1):1–19.

[8] Coelho, L. C., Renaud, J., and Laporte, G. (2016). Road-based goods transportation: a survey of real-world logistics applications from 2000 to 2015. INFOR: Information Systems and Operational Research, 54(2):79–96.

[9] Desrosiers, J., Laporte, G., Sauve, M., Soumis, F., and Taillefer, S. (1988). Vehicle routing with full loads. Computers & Operations Research, 15(3):219–226.

[10] EM-DAT (2014). EM-DAT. The international disaster database. [Online]. Available from: https://www.emdat.be/guidelines. Accessed in 2021.

[11] Hartmann, S. and Briskorn, D. (2010). A survey of variants and extensions of the resource-constrained project scheduling problem. European Journal of operational research, 207(1):1–14.

[12] Henderson, D., Jacobson, S. H., and Johnson, A. W. (2003). The theory and practice of simulated annealing. In Handbook of metaheuristics, pages 287–319. Springer.

[13] Júnior, A. d. C. G., Souza, M. J. F., and Martins, A. X. (2005). Simulated annealing aplicado à resolução do problema de roteamento de veículos com janela de tempo. TRANSPORTES, 13(2).

[14] Pritsker, A. A. B., Waiters, L. J., and Wolfe, P. M. (1969). Multiproject scheduling with limited resources: A zero-one programming approach. Management science, 16(1):93–108.

[15] Prodhon, C. and Prins, C. (2014). A survey of recent research on location-routing problems. European Journal of Operational Research, 238(1):1–17.

[16] Sakuraba, C. S., Santos, A. C., Prins, C., Bouillot, L., Durand, A., and Allenbach, B. (2016). Road network emergency accessibility planning after a major earthquake. EURO Journal on Computational Optimization, 4(3-4):381–402.

[17] Soares, R., Marques, A., Amorim, P., and Rasinmäki, J. (2019). Multiple vehicle synchronisation in a full truck-load pickup and delivery problem: A case-study in the biomass supply chain. European Journal of Operational Research, 277(1):174–194.

[18] United Nations (2018). World population in urban areas. [Online]. Available from: https://www.un.org/development/desa/en/news/ population/2018-revision-of-world-urbanization-prospects.html. Accessed in 2021.

Selection method of DRT systems

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Abstract
Demand responsive transport system is flexible travel solution, in which the public transport vehicle does not have a fixed route and timetable, but the destinations and stops are organized according to the travel demands. DRT solutions are widespread all over the world and this application mostly depends on the service area and its time. These systems are applied in sparsely populated areas and suburbs, usually off-peak hours. This article presents the specifics of DRT systems and the necessary conditions for their application. Moreover, a selection method is drawn up between the different levels of flexibility.

1. Introduction
The personal- and the public transportation is the most common area of our lifestyle. It can be a combination of personal- and public means of transport to travel between the A and B points.

Personal transport:
- walking,
- bicycle,
- motorcycle,
- car-carsharing (max. 1-2 persons),
- roller, etc.
- and their electrical alternatives.

Public transport:
- bus,
- train,
- tram,
- metro,
- airplane,
- boat,
- car-pooling, etc.

In the case of vehicles used in personal transport, the energy is invested only to serve the travel needs of one person. In contrast to the use of public transport, where specific routes are defined to meet the needs of more passengers, achieving less energy consumption per unit with limited flexibility on the road. [1] It can be stated that the car is an exception among the individual means of transport, because all the other means of transport can be used only in a short way and are of low comfort. Thus, long-distance journeys can be efficiently achieved by public transport, but in each case they are supplemented by another means of public or private transport due to leaving the starting point and reaching the final destination.[2] The characteristics of the categories of passenger transport provided as a service are shown in the following figure, as a function of capacity and unit cost.

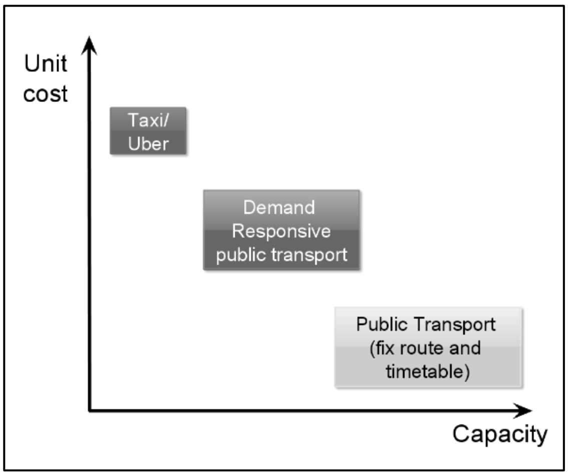


Figure 1: Types of passenger transport according to flexibility [3]

The most flexible transport service for the personal travel needs is the taxi, but more recently, business-like carsharing services have emerged that have conquered the densely populated big cities. [4] With these services, door-to-door passenger transport can be easily implemented with great flexibility but it comes at a high cost. The other case is traditional public transport, where the service takes place on a fixed route with a determined journey time. The unit cost is low in the public transport, although a number of things are attached to the cost such as frequency, fixed timetable, capacity, fixed route and stops.
Among the types of passenger transport, which were presented earlier, the demand responsive public service (DRT) flexibly contents the needs of passengers. (Figure 1.) Demand responsive transport system is a flexible travel solution, in which the public transport vehicle does not have a fixed route and timetable, but the routes and stops are organized according to the travel demands. DRT aims to reduce the use of resources in a way that makes it more competitive compared to scheduled services.
The aim of this research is to present the characteristics of demand responsive transport systems and the flexible solutions that can be applied in the case of traditional public transport systems, and to summarize the selection proposals required for the design of DRT systems.

2. DRT literature review

In 2.1 subchapter, the main literature analysis; In 2.2 subchapter general overview of DRT systems are presented.

2.1. Literature

By examining demand responsive or flexible transport in popular literature databases, it can be concluded, that the topic has been moderately yet continuously researched, but articles and journals on DRT have doubled in the last few years. The study was based on the Scopus, Researchgate, and Google Scholar databases. It can be seen in Figure 2 that between 2012 and 2019, an average of 13-16 publications were published annually in the Scopus database. In 2020, there was an outstanding value, that certainly will be repeated, because in the first quarter of 2021, 11 articles have already been registered on this topic.

Most of the articles were written in the US and western EU countries. This makes it possible to establish the fact that the DRT service has spread mainly in the more developed countries, and that significant research has been carried out into the development of flexible transport systems.

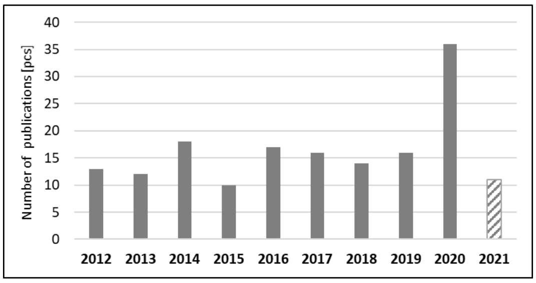


Figure 2: Number of DRT publications in Scopus

Major publications on DRT include: modeling [5], fare calculation [6], travel satisfaction and attitude [7], mobility effects , territorial coverage of traditional public transport networks, use of autonomus vehicles in transport [9], last mile theory [10], market models, e-mobility, case studies of applied systems, etc. In many countries, national regulations do not allow public service DRTs, but only in the private sector.

2.2. General overview of DRT systems

Meanwhile examining DRT systems, it is worth reviewing the flexible transport services that have worked well so far, from which important information or best practice come, which can also contribute to the results of this article.
Flexible passenger transport systems in the private sector that is usually linked to other activities:

- humanitarian services (transport of patients and people with reduced mobility);
- transportation of students → school bus;
- managing work-oriented travel needs;
- airport transfer → shuttle bus;
- as a supplement or alternative to traditional public transport;
- other special purposes.

The DRT service performs support for a specific activity or solves a problem, as listed above. In the case of schools, the task is a classic morning collection and then an afternoon distribution vehicle routing problem solving, where the route and stops is mostly constant. The route traveled usually changes annually. [11]
Patient transport is usually based on prior announcements, for example, until the end of the previous day's working hours, after which morning and afternoon route are usually scheduled the next day. In this case, the route is planned according to daily changing needs.
Organizing the collection and distribution of the human resources of multinational companies is a more complicated task than before. In the long term, the work scheduling of employees, the even workload and the geographical distance between their places of residence must be taken into account when planning routes. In addition, informing employees about the time of arrival and

departure at the stops should be resolved. The path of the routes does not match on any day, but adapting to the work schedule and providing information is an important aspect of the effectiveness of this route organization principle.
The application of shuttle buses as a service in the time before COVID provided an efficient and competitive service with proper organization and good passenger information. Currently, demand is low for this service, but it had to be possible to plan several collection and distribution route per day to meet the high demands of all passengers. Typical round VRP, as in most cases there are one or a maximum of two airports close to each other in a large city.
The previous service types are only available to a closed community. The opening up of DRT systems to the community can be made available by public transport companies. In some countries, it was not possible to provide a flexible public transport service. [12]
In Hungary, it has been possible to provide flexible public transport services according to the regulations laid down in legislation since 2014.

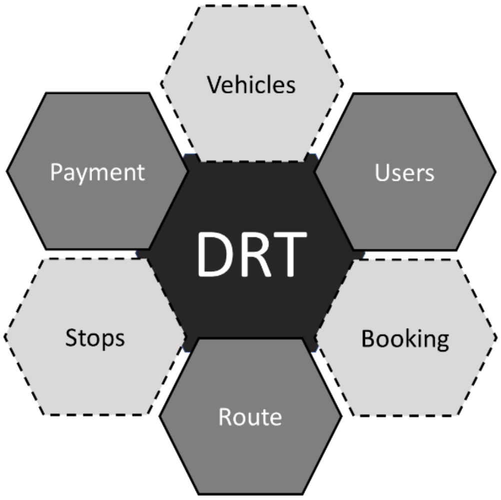


Figure 3: Main parameters of DRT systems in traditional public transportation

Demand responsive public transport systems are more complex than the service models presented above. The service is open to everyone, but the possibility of use depends on the booking options. The most common booking process is check-in by phone, which must be submitted significantly earlier than the travel request would be planned. In this case, the exact location of the get on and get off point must be provided by telephone. The dispatcher will then provide the traveler with feedback on the travel request status. With the rise of information and communication technology, it is possible to extend the booking to the DRT service via a smartphone, which can further increase the data exchange and information flow between the service provider and the passenger declaring the travel request. If this option is workable, then the possibility of telephone login cannot be displaced either, as the older generation (who prefer to use public transport) is not expected to use smart mobile devices.
The size of the vehicles that used in the DRT service varies, but is usually a mini- and microbus. Primarily because DRT aims to provide low-volume routes at the lowest possible unit cost. Greater flexibility can be allowed in the organization of trips, for example for 10 passengers than for 75 passengers as shown in Figure 4. Furthermore, one of the main applications of demand responsive transportation systems is hard-to-reach places, dangerous or sparsely populated areas where there is little demand for travel but residents need to be provided with transportation. Therefore, these small communities do not need to provide large buses.

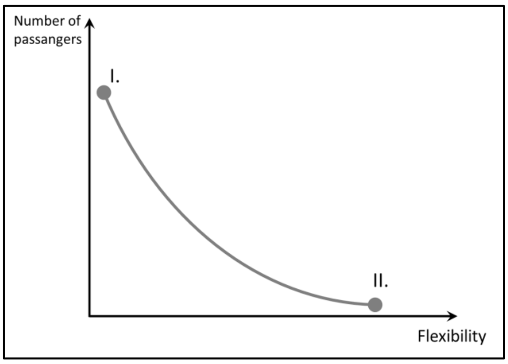


Figure 4: Relationship between flexibility and number of passengers in DRT systems

- **I. option:** high number of passengers, so the flexibility of the passenger transport system is low.
- **II.** option**:** minimum number of passengers, which makes the system flexible.

It can be concluded that the flexibility of the DRT system is provided by the the cost-effectiveness and low number of passengers furthermore specifics of the region.
A very important parameter has not yet been mentioned, which is the tariff. The tariff of the public DRT system is lower than its pricing in the private sector, but it differs from the fares used in classical public transport. This factor depends on whether local or long distance is the DRT. In the case of a local service, the price of a normal line ticket can be used, but in the case of long-distance transport, the fare calculation can be done on a distance or time basis. In the event of delays or longer detours, a discount system can be introduced intelligently for further promotion.

2.3. Stops and routes in DRT systems

The DRT parameters described so far can be said to be general, because the design of a flexible transport system is mainly determined by the road and stops and their additional parameters. Selection suggestions and advice to help design a DRT service will depend on these two key network elements.

The connection between the route and the stops is similar to that in traditional public transport in that the road is created by connecting the stops. The fixed route and the stops built are also important for the unobstructed interoperability of large conventional public transport vehicles. However, another aspect of the flexibility of the DRT system is that with a smaller capacity vehicle, the route between the two stops can be freely changed according to the rules of the road. The length and structure of the road depends on the stops. Stops are, in most cases, places where travel needs arise. They can be fixed stops, conditional stops or individual points according to the transport system. The points of demands of the requests and the desired destinations can determine the direction of the route of the given line.

3. Selection of DRT systems

In the following paragraphs, the constraints of the traditional public transport service will be described, and we will be able to move from the description of increasingly flexible systems to the characterization of a fully demand responsive transport service. Each type will also be accompanied by a schematic figure and a suggested service area.

3.1. Fixed route and stops

This type is exactly the same as the traditional public transport service. The line affects all mandatory stops, thus following the fixed route. The vehicle stops are affected by the order in the schedule, where the arrival and departure times are known. (5. Figure) There is no flexibility at this level as stopping at stops is done according to needs. A stop occurs when there is a passenger at the stop or a landing request from a passenger on the vehicle. Furthermore, it also depends on whether or not it is mandatory for the vehicle to stop at all stops, regardless of the change of passengers.

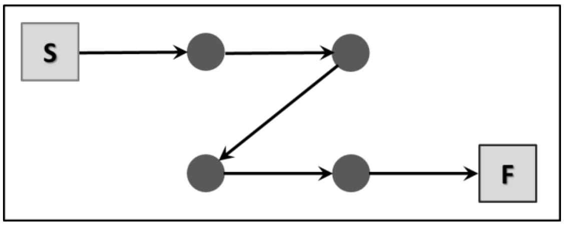


Figure 5: Schematic network of fixed route and stops

In the previous system, there is a flexible version where some stops in the schedule are included as conditional points. (6. Figure) In this case, the scheduled departure times will be indicated in the schedule. This type differs minimally from the traditional public transport service, but the announced timetable already includes flexible transport solutions.

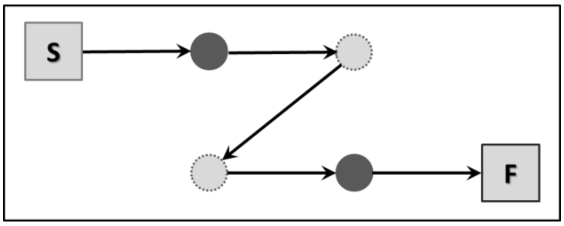


Figure 6: Schematic network of fixed route with some conditional stops

3.2. Partly fixed route and stops

In the case of partly fixed public transport, flexible solutions need to be used more widely and the problem of dealing with external travel needs is emerging.

3.2.1. Route extension from start or ending stop

Conditional stops connected to the start and end points of a public transport route (fixed route / fixed stop) are served flexibly by the vehicle. (Figure 7.) Conditional stops appear in the timetable so that they are only visited upon prior notice. There is also a fixed and conditional part of the route.

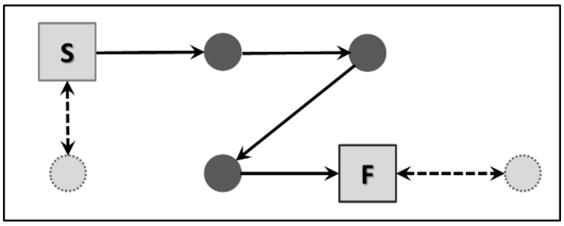


Figure 7: Schematic network of route extension from start or ending stop

Conditional stops are only served based on forecast demands. Requests can be received through a dispatcher center before the scheduled departure time of the trip. Of course, signaling the need to land at the conditional stop indicated to the driver on the fixed section is also a solution, but the intake of the first conditional stop is subject to prior registration. Several smarter solutions are starting to be used by transport service providers / companies to signal needs. Typical applications are also in large cities and in the countryside, where conditional stops are in an area that is difficult to reach or where there is low travel demand compared to fixed stops. It can be used effectively when serving night transport service or smaller residential areas.

3.2.2. Route extension with by-pass route(s)

On many scheduled bus services, you may encounter the case where the path of the route is constructed to include several round trips or detours deviating from the main line. (8. Figure) The first option is called back and forth route by the technical language, and if there are no passengers and demand at the stops, the use of the conditional stop could be skip. The second option is when the vehicle skips a section of the backbone network of the trip and touches one or more stops with a by-pass to cover, for example, a residential area or a shopping center. These two options provide extra travel and time for passengers who may be traveling between the departing and the final stop, especially if there are no waiting or disembarking passengers at these side stops. Of course, it would also be in the interest of the service provider to eliminate the need to traverse unnecessary roads. Fortunately, these rounds of trip management can be solved with flexible transport principles.

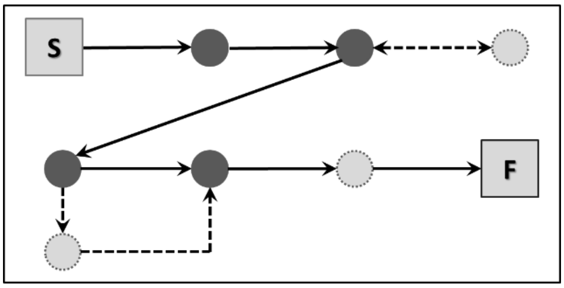


Figure 8: Schematic network of route extension with back-and-fort and by-pass

Similar to the previous problem, a flexible solution can be applied if the problematic sections are reclassified into conditional routes. The flexible solution described in the previous subsection also helps to ensure that additional by-passes are taken only in justified cases. The transport structures presented in subchapters *3, 3.2.1* and *3.2.2* can be fulfilled with larger capacity vehicles spiced with the elements of flexible transport, but in the case of the next type only the use of smaller capacity vehicles is effective.

3.2.3. Round trip

This structure already represents a higher level of transport flexibility compared to previous types. In the present case, the example shows a connecting trip (Figure 9.) because the starting and ending points of the trip are fixed and located in one place. Alternatively, the bus line could be linear, where the it connects the locations of the received requests between the fixed start and end points.

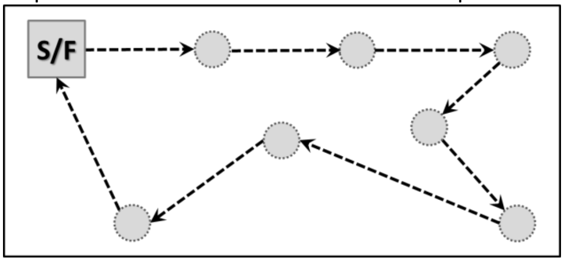


Figure 9: Schematic network of flexible route/tour

The base structure in the figure embodies one of the efficient uses of demand responsive transportation services. The base can be an airport, shopping mall, multimodal hub [13] , etc. which serve as the departure and destination points for the network of trips. This is essentially a feedback to subsection *2.2 General overview of DRT systems* where DRT private sector services based on similar foundations have been presented. The reporting of demands also deviates from the methods discussed in the previous chapters. In this case, only the individual needs determine the get on or get off points involved in a trip. Furthermore, the emergence of demands is no longer a classic public transport service with flexible elements, but an almost home-based service, so high-capacity vehicles would be an obstacle inferior road. In any case, the proposed field of application is to accommodate suburban or long-distance scheduled services with hub-and-spoke conception transport. This further helps the connection between the DRT and the last mile transport concept. Last but not least, flexible passenger transport related to serving frequented locations is another competitive option.

3.3. Free route organization

This option is obviously the highlight in terms of the flexibility of transport systems. (Figure 10.) Although flexibility cannot be increased to the extremes, because then there will be as high unit costs as in the case of taxi and carsharing. It is advisable to divide the fully self-organizing DRT service into service zones, as the service will no longer be predictable if the wide range of requests is automatically accepted. And this is reflected in efficiency and competitiveness.

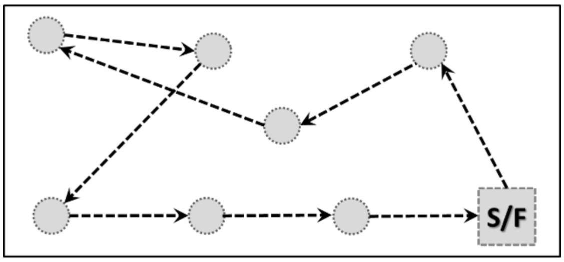
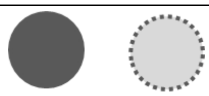
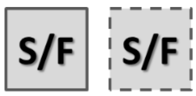


Figure 10: Schematic network of fully demand responsive route

In order for the self-organizing DRT service to work efficiently, it is no longer enough to forecast travel needs over the phone, but to apply via a platform developed for mobile communication devices, which can continuously show the current availability of the service you want to use. The notation explanation of Figures 5-6-7-8-9-10. is provided in the following table. These figures are made description of [14] reference.

Table 1: Notations of 5-6-7-8-9-10 figures

Symbol	Meaning
	Fixed, partly-fixed route
	Fixed, partly-fixed stops
	Fixed, partly-fixed start starting and ending points

4. Summary

The use of demand responsive transport systems is different compared to traditional transportation systems. It is not applicable to all public transport situations and services, such as railway transportation, where flexible application simply does not make sense. In many cases, a public transport companies do not take the risk and do not invest extra energy to use flexible transport systems in contrast fixed-schedule transport services. This article demonstrates that there are a number of options for using flexible solutions in a traditional road public transport service that can save significant extra energy, thus cost, by applying it at the right time and place. The start of using of DRT must correspond to the specific characteristics of the service area in question, because flexible transport is a stochastic system where saturation is difficult to predict. It can be seen that DRT is not only a service where trips are tailored solely to the current needs of passengers, but also a flexible transformation of traditional public transport that contains of several stages. Hopefully, these results can help encourage transport companies to apply flexible transport systems and there will be an increase in research on DRT (Demand Responsive Systems) and FTS (Flexible Transport Systems).

5. References

[1] Kelemen-Erdos, A. (2012): Sustainable public transport: A Central European Study, Periodica Polytechnica Social and Management Sciences, 20 (2), pp. 81-90.

[2] Ryley, T.J. (2014.): Investigating the contribution of Demand Responsive Transport to a sustainable local public transport system. Research in Transportation Economics, 48, pp.364–372.

[3] Van Ieperen, J. (2006): Intelligent public transport systems the key to better mobility, Public Transport International, 55 (5), pp. 6-11.

[4] Brendel, A.B., Lichtenberg, S., Prinz, C., Herrenkind, B. (2020): Increasing the value of shared vehicles: Insights from an implementation of user-based relocation in station-based one-way carsharing, Sustainability (Switzerland), 12 (21), art. no. 8800, pp. 1-15.

[5] Inturri, G., Giuffrida, N., Ignaccolo, M., Le Pira, M., Pluchino, A., Rapisarda, A., D'Angelo, R. (2021): Taxi vs. demand responsive shared transport systems: An agent-based simulation approach, Transport Policy, 103, pp. 116-126.

[6] Andrejszki, T., Török, Á. (2012.): Intelligens rugalmas közlekedési rendszerek díjképzési módszertana. Közlekedéstudományi Szemle, I., pp.53–62.

[7] Jain, S., Ronald, N., Thompson, R., Winter, S. (2017): Predicting susceptibility to use demand responsive transport using demographic and trip characteristics of the population, Travel Behaviour and Society, 6, pp. 44-56.

[8] Camargo, P., Pammenter, E., Inayathusein, A. (2020): Mobility-as-a-Service and Demand-Responsive Transport: Practical Implementation in Traditional Forecasting Models, Transportation Research Record, 2675 (2), pp. 15-24.

[9] Bischoff, J., Führer, K., Maciejewski, M. (2019): Impact assessment of autonomous DRT systems, Transportation Research Procedia, 41, pp. 440-446.

[10] Charisis, A., Iliopoulou, C., Kepaptsoglou, K. (2018): DRT route design for the first/last mile problem: model and application to Athens, Greece, Public Transport, 10 (3), pp. 499-527.

[11] Kamruzzaman, M., Hine, J., Gunay, B., Blair, N. (2011): Using GIS to visualise and evaluate student travel behaviour, Journal of Transport Geography, 19 (1), pp. 13-32.

[12] Neven, A., Braekers, K., Declercq, K., Wets, G., Janssens, D., Bellemans, T. (2015): Assessing the impact of different policy decisions on the resource requirements of a Demand Responsive Transport system for persons with disabilities, Transport Policy, 44, pp. 48-57.

[13] Bielli, M., Boulmakoul, A., Mouncif, H. (2006): Object modeling and path computation for multimodal travel systems, European Journal of Operational Research, 175 (3), pp. 1705-1730.

[14] Viergutz, K., Brinkmann, F. (2019): Autonomous Vehicles and Future Mobility, pp. 54-75.

Methodology for improving logistical processes

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Abstract
Logistics processes must be permanently improved and optimized. For this purpose, logisticians have a large pool of methods from various scientific disciplines at their disposal. A number of methodological collections exist. (cf. e.g. [1], [2]) The Institute of Logistics and Material Handling Systems at the OVGU has also special expertise in this field. (Cf. [3], [4]) The aim of the research work is to systematically prepare essential process improvement methods and to provide them with application examples and recommendations in order to simplify their subsequent use. The aim is, among other things, to expand the methods, to compile profiles of previously undocumented methods and to develop suitable visualizations. In this way, the research work contributes to basic research as well as applied research.

1. Introduction
Today, those companies will survive in the long term that succeed in organizing and optimizing their business processes in line with customer requirements and strategy. With the help of business process management, essential business processes and all flows in the company must be sustainably improved.
Process optimization is an ongoing process and not a one-off action. It is about acting more effectively and efficiently overall.

The goals of process optimization are company-specific. They differ, but can also be transferred to others with regard to certain aspects, such as:

- Costs
- Lead time
- Quality.

Typical further aspects are e.g. flexibility, performance, safety, environment and resilience.

2. Procedure and research methods
The research procedure includes motivation and development of a goal, explanation of terms, development of an overview of methods, documentation of profiles of selected methods (including preparation and documentation of application examples according to a uniform system and derivation of application recommendations) (cf. [5]) and finally collection of research questions and identification of research needs.
Research methods are the literature analysis of relevant current German-language specialist literature and the contribution of many years of experience of the scientists involved. The literature analysis will subsequently be extended to the English-speaking world.

3. Important terms
The term "**method**" is used at very different levels of conceptual abstraction. The term "method" stands for a "planned (=methodical) procedure according to means and ends, which leads to technical skill in the solution of theoretical and

practical tasks (technical methods, working methods, advertising methods, educational methods, methods of science)". [6]
There are also many definitions of the term "**process**" in the literature [7].
A process is defined: "As a sequence of individual activities that begins at a specific point in time or through a defined event and leads or should lead to a specific end and a measurable result". Each process can be divided into individual, chained activities, whereby the individual activities can branch out among themselves. [7]
The term "**process optimization**" is composed of the term "process", which has already been defined, and the term "optimization". In this context, "optimization" has its origin in Latin and means something like "maximum or best value". "The linking of these two terms results in the claim to achieve the best possible goal or a better goal than before." [7] To be better can also be by achieving a minimum like e.g. costs.

4. Method overview

The starting point of the method overview (cf. Table 1) are basic logistic flows. These can be business processes in supply chains as well as material, information, financial or energy flow operations. They can be used to define and describe elementary, complex or integrated logistics processes. This first row of the table defines the object of consideration, the processes under consideration.
The following four table rows in Table 1 define different approaches to improving a logistical process. They can be done alone or in combination with each other. These four typical possibilities to improve processes are: (a) use of typical, well known, empirical strategies and processes (also modified and combined), (b) use of best practices, (c) define totally new processes or (d) optimize existing processes.
For (a) there is a big group of generic strategies and typical processes to realize logistics. They all have a main idea of solving logistics tasks. This is the group of proved and tested empirical knowledge. The application of this group involves the risk that only basic technologies are used. These basic processes can be adapted, modified or combined.
For (b) it is necessary to identify best practices, if not known. This requires time for the examination and evaluation of best practice solutions.
For (c) creativity is required. A new reference solution should be designed and realized. The solution should be innovative and new. The solution must have a clear novelty character in order to be distinguished from (a) and (d).
For (d) the focus lies on the improvement of existing processes. Typical aspects can be all the targets which the logistician wants and needs, e. g. cost, time, quality and value.

Table 1: Schema for systematization of strategical process knowledge in logistics to improve processes (cf. [3], [4], [8])

Aspect	Examples
General process models:	SCOR-model, material flow ~, information flow ~, financial flow ~, energy flow operations
General possibilities to improve processes:	
(a) Typical processes (Application, adap-tation/modification and combination)	JIT, JIS, KANBAN, ConWIP, Milkrun, Consignment warehouse processes, sourcing processes, VMI, Pick by vision
(b) Best practices, conveyance of solutions	Benchmarking, Analogy technique
(c) Total new processes	Business Process Reengineering, Process Reengineering, VSD
(d) Improvement of existing process.	KAIZEN, KVP, Super Methodology
Tool set with special focus on:	
Define targets and trends	TOWS, SWOT, Scenario technique
Environmentally responsible behavior	Green Supply Chains, Sustainability
Value	Value stream mapping (VSM)
Eliminate waste	Lean production, Lean techniques, Postponement Strategy
Accept no failures	Six Sigma, TQM, FMEA, Lean Six Sigma
Classic automation	Logistics 2.0 and Logistics 3.0
Digitalization and networking	Logistics 4.0, Smart Logistics Zone
Identify potential	Potential analysis
Identify weak-nesses in SC	Material flow analysis, 5 Why Method
Identify key aspects	ABC-, XYZ-, HML-, GMK-, FSN-, SDE-, SOS-, VED-, SKFO-, GOLF-Analysis (Com-pare [8] and [9])
Corporate Culture	Cultural analysis, Team work tools
Evaluation, Controlling, Communication improvement in SC	Cost-benefit-analysis; Balanced Scorecard, key factors; ECR Scorecard

Material and information flows are as important as financial flows in logistics. Financial key factors need be recorded in the logistics network and to be controlled. Important targets are profitability and liquidity of enterprises with logistics services. It is necessary to record costs and revenues as well as cash flows.

The toolbox of improvement methods starts with methods that help define strategies and capture trends. Established methods in this area are the SWOT and TOWS analysis and the scenario technique. In addition to the definition of strategies, the focus is also on the definition of measures.

A special focus can be placed on the area of sustainability and especially the environment. Approaches such as those known from the field of green logistics are helpful here.

Value stream mapping is useful when focusing on value and value-adding activities.

The same applies to the avoidance of waste. This is the large field of lean production and lean techniques.

In the area where it is about not making mistakes and not accepting mistakes, holistic method collections such as Six Sigma, TQM, FMEA and Lean Six Sigma are applied.

To reduce manual activities, one can use Logistics 2.0 and Logistics 3.0 solutions, while currently the focus is specifically on the digitalization and networking of Logistics 4.0. Methods such as the Smart Logistics Zone help to analyze, plan, design and evaluate logistics solutions of the fourth industrial revolution. If one is specifically looking for potentials or/and for weak points, one can use special analysis techniques such as potential analysis or special material flow or information analyses.

In order to reduce the complexity of improvement approaches and thus set suitable priorities, methods that group objects are helpful. The aim is to prioritize and separate what is important from what is less important.

Weaknesses can also lie explicitly in the corporate culture and in teamwork, which is why these "soft" areas should not be neglected either.

Typical for logistics is the procedure to create variants of the processes and choose the best one. Therefore, the use of the value benefit analysis and the evaluation with key factors are recommended.

Table 1 thus contains the structure of the entire process improvement knowledge and symbolizes a holistic approach, which can, of course, be extended and supplemented. The listed methods stand as a kind of type representative without claim to completeness.

5. Profiles including examples of use and recommendations for use

When preparing the profiles, the following structure was chosen: Brief description, origin, target, procedure/approach, application example and future prospects. This serves to generate an understanding of the methods and to show a possible future development of each method. In addition to looking into the past (history) and the present of use and application, this is also intended to look into the future of the further development of the method. Table 2 and Table 3 show profiles of two single methods. (cf. [5]) These are the Super methodology and Green logistics.

6. Results and Summary

Table 1 provides a new framework model for improving logistical processes. It avoids that only individual aspects are optimized while others are neglected. It enables a holistic approach, but also opens up the possibility to focus on only individual, essential aspects. For practical application, it is recommended to first discuss and prioritize the individual aspects with regard to their relevance in a workshop. From this, a project plan for the logistics process analysis can be developed. 66 profiles were developed in the research project. These can be applied in practice in a second step. In a third step, the results of the use of the profiles are compiled and condensed for a conceptual step. This is followed by the steps familiar from the PDCA cycle. This suitably combines theoretical knowledge and practical application.

7. Research needs

The theory of logistics has to be further developed. All the optimization methods and analysis tools presented in this paper are symbolic of the development of logistics from the 20th century to the present. It has become clear that logistics cannot develop without technology. Looking to the future, the authors believe that the future of logistics will be strongly linked to current technologies such as artificial intelligence, big data and the Internet of Things.
The following is a list of analysis tools and optimization methods (in alphabetical order) that were found within the research work but could not be processed due to time constraints:

- BOA;
- Build-to-Forecast;
- EFQM Model;
- Cluster Analysis;
- Conjoint Analysis;
- Carbon Footprint;
- Delphi Method;
- DEMI Model;
- Design Thinking;
- Efficiency Analysis;
- Environmental-Life Cycle Assessment
- Expert Interview;
- Design for Manufacturing;
- Functional Analysis;
- Ishikawa Diagram;
- Net present value method;
- KEA analysis;
- Life cycle assessment;
- Material input analysis;
- Morphological box;
- MRP III;
- Opportunity-Risk Analysis;
- Pairwise comparison;
- Qualitative interview;
- Quality function deployment;
- Quantitative interview;
- Social life cycle assessment;
- Strengths/weaknesses analysis;
- Strong sustainability;
- Supply Chain 4.0;
- Sustainability Hot Spot Analysis;
- Sustainable Economy Framework;
- Sustainability Innovation Cube;
- Scenario Analysis;
- Target Costing (Budgeting);
- Technology Calendar;
- Technology Portfolio;
- TPM (Total Productive Maintenance);
- Water Footprint.

Table 2: Profile 13: Super methodology (cf. [5])

Profile Nr.: 13	*Profile Title: Super Methodology*	*Litera-ture*
Brief description	*The Super Methodology is a five-step improvement strategy designed to improve overall productivity. It serves as a roadmap to move a process from its current state to a guided path to better performance.*	*[10] p. 705; [11]*
Origin	*"Super" was developed with the industrial environment in Hongkong/China.*	*[10] p. 705*
Target	Improve operating performance	*[10] p. 705*
Procedure	"Super" is an acronym for: (1) **S**elect the process (2) **U**nderstand the process (3) **P**roceed with the process measurement (4) **E**xecute the process improvement und (5) **R**eview of the improved process and corresponds to the approach of the methodology.	*[10] p. 689*
Application example	Bold Ware Optical Manufactory Limited is a Hongkong-based company that manufactures optical frames and sunglasses. It used the "Super methodology" to improve operational performance and thus minimize customer dissatisfaction rates.	*[10] p. 694*
Future prospects	The "Super methodology" is so far poorly represented in the literature, which indicates a low dissemination of the methodology. Therefore, a possible future development is conceivable that will make this methodology better known beyond China's borders and thus generate more applications.	
Created 12.12.2020, Roy Börner		

Table 3: Profile 24: Green logistics (cf. [5])

Profile Nr.: 24	*Profile Title: Green Logistics*	*Litera-ture*
Brief description	Green Logistics is the holistic transformation of logistics strategies, structures, processes and systems in companies and company networks to create environmentally sound and resource-efficient logistics processes.	*[12]*
Origin	The emergence of environmental policy took place at the same time as the development of an ever-growing environmental awareness in society in the 1970s. Over the years, increasing pressure from society and politics developed, which later gave rise to Green Logistics.	*[13] p. 4*
Target	Reduce resource consumption and pollution from logistical processes, which manifest themselves in exhaust emissions, water and soil pollution, and land consumption.	*[14]*
Procedure	1. analysis of the initial situation 2. definition of objectives 3. development of a Green Logistics concept 4. drawing up an individual system for recording and evaluating logistics from the point of view of sustainability 5. development of a system for the presentation of Green Logistics effects for the company 6. evaluation of set priorities for individual supply chains as examples 7. systematic development of scenarios 8. deriving options for action 9. development and implementation of a communication strategy	*[15]*

Application example	A typical practical example of green logistics and measures at different decision-making levels is a company's decision for a central warehouse strategy in distribution. The structural decision for a central warehouse initially represents a fixed point at the process level. A partial range of articles is distributed from the central warehouse to the entire delivery area. This influences the total kilometers travelled and thus the costs for fuel requirements. These costs can be reduced by Green Logistics optimization measures at subsequent levels, e.g. by using route planning software or fleet control systems.	*[12]*
Future prospects	Industry-wide penetration of Green Logistics with 3D printing, fleet management systems, electromobility and a qualification of driving personnel on fuel-saving driving style.	*[16] p. 48*
	Created 08.01.21, Roy Börner	

8. References

[1] Becker, T. (2018): Prozesse in Produktion und Supply Chain optimieren. o.O. Springer Verlag

[2] Schawel, F.B. (2014): Top 100 Management Tools. Wiesbaden: Gabler-Verlag

[3] Glistau, E.; Coello Machado, N. I. (2019): Logistics 4.0 - basics, ideas and useful methods. In: MultiScience - XXXIII. microCAD International Multidisciplinary Scientific Conference - Miskolc: University of Miskolc, Hungary, total 7 pages.

[4] Glistau, E.; Coello Machado, N. I. (2019): Logistics 4.0 - solutions and trends. In: Conference: COMEC2019, June, 23th-30th, Cayos de Villa Clara, Cuba. total 13 pages.

[5] Börner, R.; Wang, Y.; Zeneli, T. (2021): Methoden der Verbesserung logistischer Prozesse: Theorie und praktische Anwendung. Master´s project thesis. Supervisor: Elke Glistau. Otto-von-Guericke University Magdeburg, 89 pages.

[6] Bellers, J. (1989). Analyse internationaler Beziehungen. Wiesbaden: Springer Fachmedien Wiesbaden. P. 11

[7] Kruse, W. (2009): Prozessoptimierung am Beispiel der Einführung eines neuen selbstverantwortlichen Arbeitsplanungsmodells im Hanse-Klinikum Wismar. o.O.: BoD – Books on Demand. pp. 64-67

[8] Glistau E.; Coello Machado, N. I. (2016): Tools for improving logistics processes. In: Annals of the Faculty of Engineering Hunedoara: International Journal of Engineering - Hunedoara: University Politehnica Timisoara, Faculty of Engineering Hunedoara, Vol. 14., Art. 33, 6 pages.

[9] Koch, M. (2010): Object analyses in logistics. In: Proceedings of the XIII LOGMARK 2010 Conference: Editora Logicuba. Las Tunas, Cuba. 6 pages.

[10] Chuah, K. L. (2001): A SUPER methodology for business process improvement - An industrial case study in Hong Kong/China. o.O.: International Journal of Operations & Production Management 21(5/6): pp. 687-706.

[11] Mosimtec. (w.D.). www.mosimtec.com. Retrieved on 10. 12 2020 from https://mosimtec.com/business-process-improvement-methodology/

[12) Orgaplan Logistik GmbH. (w.D.). www.orgaplan-logistik.de. Retrieved on 05. 01 2021 from https://www.orgaplan-logistik.de/strategie/green-logistics/

[13) Reichelt, I. (2017). www.grin.com. Retrieved on 06. 01 2021 from https://www.grin.com/document/379658

[14] Saloodo! GmbH. (2020). www.saloodo.com. Retrieved on 05. 01 2021 from https://www.saloodo.com/de/logistik-lexikon/gruene-logistik/

[15] TCW Transfer-Centrum für Produktions-Logistik und. (o.D.). www.tcw.de. Retrieved on 05. 01 2021 from https://www.tcw.de/beratungsleistungen/logistikmanagement/green-logistics-375

[16] Lohre, D.; Herschlein, S. (2010). Grüne Logistik - Studie zu Begriffsverständnis, Bedeutung und Verbreitung „Grüner Logistik“ in der Speditions- und Logistikbranche. Bonn: Deutscher Speditions- und Logistikverband e.V.

Certification of the warehouse in rum factory

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Abstract

Today's business world is becoming increasingly complex and unpredictable for companies. The accelerated development of science and technology, together with the globalization of the market, makes organizations face the need to find solutions that ensure their position in the market, lead to optimizing processes and make them more competitive. An important aspect in this regard is the certification of the entire process, including the warehouse areas. In the research, an extensive review of the current literature was carried out, especially the current resolutions, which allowed us to incorporate elements of logistics 4.0 and human-machine interaction. A procedure is developed that allows self-evaluation according to the level of certification that is chosen. Quality management tools are used, the application increases in complexity as excellence is sought in the storage of finished products. The case study is carried out as a way to improve the current certification level of the finished products warehouse at the Cuban Rum factory.

1. Introduction

Starting in the new millennium, different norms and resolutions were created in Cuba that regulate the procedure to certify storage systems in the country; as well as who was authorized to categorize them. Since 2007, with Resolution 153 [1], one of the first steps was taken in the creation of a logistics file (EXPELOG) that allows evaluating storage systems in companies; later it is complemented by other subsequent resolutions that consolidate the implementation in Cuba. In 2020, the accreditation procedure for storage systems and the requirements to achieve the certifications in Resolution 47 [2] are updated. In addition, Resolution 64 [3] creates the National Commission of Experts in Warehouse Logistics, with the aim of controlling and certifying everything related to the category obtained by warehouses in the country and the content of the courses for overcoming logistics in warehouses.

Among the methodological tools consulted, several were found that contributed national and international authors. From the study of them, it was found that they have relevant aspects such as Lean Logistics and the different national procedures for the improvement of warehouse logistics. In warehouse logistics it is always necessary to adjust the types of stored products, aspects related to the warehouse itself, international experiences and the appearance of new national regulations, in addition to that this procedure can be better structured. The entry into force in May 2020 of the new regulation, places the rum factory in a position for improvement, since it was certified with the first technical level by said regulation. The senior management of the company and the Cuba Ron group is not satisfied with the result achieved, because the first technical level of certification is the lowest of the categories awarded.

According to the aforementioned, the general objective is defined as: to improve the logistics of the finished products warehouse of the Central Rum Factory. To achieve the general objective set, the following specific objectives are established:

- Carry out an extensive bibliographic review, which allows to have all the theoretical bases and fundamental applications related to the research topic.
- Design a procedure for the continuous improvement of the storage logistics of the different presentations of Cuban rum.
- Apply the proposed procedure to the finished products warehouse of the Central Rum Factory.

2. Research background

The theoretical framework is the search and study of all the bibliography that is directly related to the research topic [4]. Based on the above, the need for the subject under study, the research and analysis of the international and national specialized literature, the review of the state of the art and the practice on the subject of warehouse management in logistics chains in general is raised and in particular the logistics chains in the production of beverages.

2.1. Logistics and Supply Chain Management

The current literature registers more than 35 terminologies to refer to logistics: complexes with an integrating, systemic and rationalizing concept, fundamentally oriented to the satisfaction of the end customer of the chain, with the minimum costs and the quality and the time required and the quantity and place specified; or simple to give a general idea of the objectives and functions that it pursues. Researchers and companies use them interchangeably according to the circumstances and objectives they intend to achieve. Some of these authors are: [5], [6], [7], [8], [9] define that: logistics is that part of Supply Chain Management, which plans, implements and controls the direct and reverse flow and the effective and efficient storage of goods and services, with all the information related from the point of view of origin to the point of view of consumption, in order to meet customer requirements. As can be seen, there are many coincidences in the existing definitions that can be summarized in that logistics is a system that includes the processes of supply, production, distribution, marketing and its inverse chain, which are developed between suppliers and customers, implying the effective and efficient management of material, financial, information and waste flows, taking customer satisfaction as a premise [10].

2.2. Industry 4.0

Currently the world is entering the fourth industrial revolution, which is named by various authors as the digital revolution or Industry 4.0, where the role of digitization and computer interconnectivity within Industries is prioritized. The term "Industry 4.0" was first used in a German government high-tech strategy project. It is based on software nomenclature and is used as a synonym for the fourth industrial revolution. The basic concepts of Industry 4.0 guarantee the availability of relevant information in real time through the network connection of all the elements involved in the creation of value, the ability to deduce optimal value-added processes from information and data at any time and the realization of an information of the integrated process of the added value [11]. The relevant technologies of Logistics 4.0 are: identification, mobile communication, location, electronic data interchange, data analysis methods and data analysis processing [12]. This includes transportation, warehouses and the management of raw materials and finished productions. In this paper, the fourth industrial revolution or Industry 4.0 of the logistics that accompanies this evolution is approached and with this it is also appropriate to identify Warehouses 4.0 [13]. Although these technologies are far from the possibilities of most countries, including Cuba, in all their dimensions, their knowledge is interesting. The interconnection between solutions and software, together with robotics and the management of interaction with people, which connects flexible and intelligent automated solutions with the ability to scale and adapt to change, are a part of version 4.0 of warehouses. For several years now, there have been various automation systems on the market specially designed to provide automatic collection and storage solutions, which allow increasing productivity indicators, reducing the number of movements, transport tasks and space [14].

2.3. Certifications

Considering the author's idea, [15] companies require a rational use of limited resources (inventories, human capital, equipment, space and economic resources). Either in the administration of medicines, industrial supplies, perishable products, electronics, fabrics, food, beverages and others. It is not only important to maintain optimal inventory levels, but also to keep your properties in good condition and make sure that the worker performs their work in safe environments, so that the offer to the client is correct. Based on their concept of "due diligence" (the ability to be able to demonstrate that all reasonable measures have been taken to avoid an incident), European retailers have established specific rules to ensure the quality of goods in logistics food (and non-food) products, safety and legality in the CS of food and beverages. Food safety standards such as:

- The English British Retail Consortium (BRC)
- The German International Features Standards (IFS)
- The Australian Small Quantity Generator (SQG)
- The Dutch Hazard Analysis Critical Control Point (HACCP)

These standards are safe and operational management systems, applicable to both food and non-food products. They were created to ensure supplier compliance, considering storage, transportation and distribution, to ensure the skills of the retailer and guarantee the quality and safety of the food products they sell [16]. All these certifications have one point in common, the standards for storing the products to be evaluated. This is caused by the different priorities that countries give to products and their storage conditions.

2.3.1. Warehouse certification regulations at the national level

The Ministry of Internal Commerce (MINCIN) is the governing body of the logistics activity of warehouses in Cuba and therefore in charge of regulating the development of this discipline in the national territory. The most important resolutions related to warehouse activity and those that are currently in force are briefly explained below. These are:

Resolution 47/2020 [2] defines as objectives: to establish the main regulations in the processes, activities and operations in the logistics of warehouses of the entities that operate in the national economy and to increase the effectiveness and efficiency of the processes, activities and operations related to warehouse logistics based on continuous improvement. It clarifies the organisms with regulatory functions that interact with the warehouses. It also explains that: EXPELOG is a mandatory tool for use in the warehouse and a
necessary aspect for its categorization. Referring to the categorization of warehouses, the resolution states "The categorization process is an institutional act that is executed free of charge, to achieve greater effectiveness in warehouse logistics processes." It is carried out according to the technological levels:

- First level: When the products are stored in conditions that guarantee an adequate control and conservation of the same.
- Second level: When an adequate organization and operation of the warehouse is achieved.
- Third level: When a correct operation of the warehouse is carried out with a focus on the customer and constitutes a reference warehouse.
- Uncategorized: When a requirement is breached in the evaluation process for the First Level categorization.

The National Commission of Warehouse Logistics Experts is regulated by Resolution 64/2020 [3]. This resolution establishes the members and the hierarchy in the commission; as well as its responsibility in the fulfillment of logistics activities. In this study, the resolutions issued at the country level in 2020 will be considered, in the case of the storage of supplies and products in general and in the case of beverages in particular.

3. Methodology

The procedure developed is the result of the bibliographic analysis carried out, as it contains in a rational way what was raised by the different authors regarding warehouse logistics, the different resolutions in force in the country related to this activity and the different certifications studied are shown in the Figure 1.

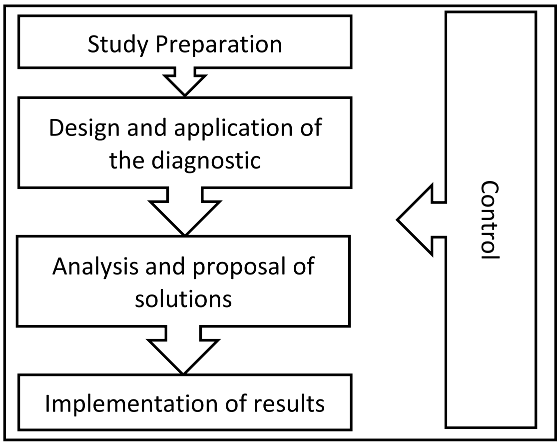

Figure 1: Methodology

3.1. Study Preparation

The characterization of the current situation, as a first step or stage of work, is important to have a general knowledge of the organization and in particular of the warehouse studied. For this, it is necessary to describe a whole set of aspects that are detailed below: the corporate purpose, the mission, the vision, the integrated management policy, the product lines, the strategic analysis of the organization, the distribution of the warehouse floor plan., the analysis of the storage technology, the technical state of the equipment, among others. As the object of practical study is a logistics operator, all the elements described come together in the same organization. In the case of warehouses that exist in companies whose corporate purpose is not a logistics service, it is necessary to differentiate those that characterize the organization from those of the warehouse, although they must also be present.

When assessing the requirements and restrictions demanded by stored products, compliance with the standards and resolutions established for each type of product stored or intended to be stored must be considered, as well as the specifications described by the manufacturers in terms of its handling, storage and conservation. It is necessary to evaluate all the activities that take place in the warehouse in order to guarantee the correct handling and conservation, since this result can lead to a significant reduction in logistics costs. The result of this assessment will make it possible to evaluate the effectiveness of the type of installation selected, and to propose the optimal-viable technological variant to achieve the best management results. All the requirements and restrictions demanded by the products and the warehouse under study.

3.2. Design and application of the diagnostic tool

This stage of work constitutes the core of the diagnosis that is made to the warehouse and includes the study of the physical installation and its management, preferably in a qualitative and quantitative way. The aspects that must be analyzed are: use of space, warehouse organization, reception and dispatch of merchandise, planning and control, documentation, protection and security, and conservation standards.

For the evaluation, several essential tools were used that are analyzed in the system since they complement each other. These are: checklist (prepared to detect problems from a qualitative point of view), storage space utilization indicators, warehouse operation and customer service indicators and cause-effect diagram, which constitutes a qualitative tool, recommended in this case to integrate all the problems detected graphically. In Table 1 you can see a summary of the checklists and their scores by key areas. It is important to point out that to reach a level of categorization it is necessary to comply with all the aspects of the previous level and the level chosen. This is represented in the checklists, as this avoids the loss of achievements that had already been achieved. The three checklists will have a value of 100 points each, although the values of the evaluated areas and the aspects vary according to the technological level.

In the investigation, checklist 2 is applied, as an example some of its unique characteristics are highlighted in the points that most affect the evaluation of the warehouse. These are:

Table 1: Summary of the areas and evaluations in the checklists

Checklist 1		**Checklist 2**		**Checklist 3**	
Aspects to evaluate	Points	Aspects to evaluate	Points	Aspects to evaluate	Points
Constructive state	10	Constructive state	10	Constructive state	10
-	-	Use of space	10	Use of space	10
Warehouse organization	30	Warehouse organization	20	Warehouse organization	15
Planification and control	15	Planification and control	10	Reception and dispatch of the merchandise	10
Documentation in the warehouse	10	Documentation in the warehouse	10	Planification and control	10
Conservation and pest control standards	10	Conservation and pest control standards	10	Documentation in the warehouse	15
Protection, Safety and health of workers	15	Protection, Safety and health of workers	10	Conservation and pest control standards	10
-	-	Equipment	&	Protection, Safety and health of workers	10
-	-	Cleaning and disinfection	10	Equipment	&
Product contamination	10	Product contamination	10	Product contamination; cleaning and disinfection	10
Total	100	Total	100	Total	100

- Use of space:
- Computer organization of the warehouse.
- Work with scanner and codes in secondary packaging.
- Use of machinery to avoid double manipulation.
- Warehouse organization:
- Efficiency of control methods.
- Construction facilities for reception and dispatch.
- Procedures or technologies to reduce manipulation.
- Training of workers in logistics and use of equipment in their work area.
- Warehouse documentation
- Efficiency of control methods
- Traceability
- Computer skills and data processing.
- Equipment
- Warehouse connectivity is connected to the factory computer network or the company's cloud.
- Human-machine interaction with the warehouse's automatic or semi-automatic activities

Also clarify that the higher the technological level, the more areas to evaluate appear and there are differences in the score of the areas at the different levels.

3.3. Analysis and solution proposals

For the development of the corrective action, we start from an analysis of the storage technology. This factor is decisive to define the storage method to select. Once the problems have been identified, the proposal of a set of measures aimed at eliminating or minimizing the problems detected corresponds. For the execution of the corrective measures, the conditions of the warehouse and the factory product must be taken into account, where possible solutions tend to increase economic results and customer service. For the generation of corrective measures, the use of the expert method known as Brainstorming is recommended, in which workers, specialists and managers must participate, the following being essential: quality specialist, warehouse employees, economic specialist, commercial manager (recommended as facilitator), members of the inventory commission, business analyst, distribution specialist.

3.4. Implementation of the results

This stage of work constitutes an ordering of the results of the previous step. The aim is to develop an implementation plan for the proposed corrective measures. The plan must have the following data: deficiency, measure, responsible, participants and date of fulfillment.

At this stage, the application of the technological reorganization design of the warehouse is proposed for a test period of 6 months. The commercial manager will systematically bring together those responsible for applying each measure and verifying compliance with the implementation plan. If any corrective action requires staff training, this manager will coordinate with the human resources area.

3.5. Control

The last step of the procedure is a control loop that allows rectifying any deviation that is detected in the 6-month period of warehouse operation. The checklist and the indicators proposed in the diagnosis stage are used again to verify if the problems have been mitigated or eliminated and the indicators meet the requirements established by Resolution 47/2020 [2]. If this does not happen, return to the work step of the corresponding procedure and repeat the rest of the procedure. Instead, if the warehouse is ready for categorization, the EXPELOG is made, with the format suggested in the aforementioned resolution.

4. Results

The warehouse is in the first level of categorization, the checklist is applied to obtain the second level of categorization; a value of *67.40* points is obtained. The warehouse is considered to have a fair rating. In the following figures 2-5 are shown the aspects that presented the greatest difficulties in the application of checklist 2:

No.		Aspectos a evaluar	Calificación a Obtener	Calificación del Almacén	Observaciones
		Aprovechamiento del espacio.	**10**	**5.5**	
8		Tiene señalizadas las áreas de recepción y despacho.	0.5	0.5	
9		No tiene productos bloqueados que implique una doble manipulación	1	0	
10		Tiene definida un área para los productos deteriorados, separada del resto de los productos.	1	1	
11		Tiene área definida para el almacenamiento de los medios unitarizadores vacíos	1	1	
12		Poseen cerca perimetral en almacenes a cielo abierto, base de almacenes, o en aquellos techados que así lo requieran	1	1	
13		Aplicación de normas y técnicas para el empleo de medios unitarizadores.	1	1	
14		Empleo esquemas de óptima carga de medios unitarizadores. (Siempre, Ocasional, Nunca)	0.5	0.5	
15		Cumplimiento de las marcas gráficas en embalaje secundario. (Siempre, Ocasional, Nunca)	0.5	0.5	
16		Se cumple con la altura de los alojamientos de las estanterías.	0.5	0	
17		Se cumple el aprovechamiento de las estanterías.	0.5	0	
18		Se cumple con la altura de las mercancías que se encuentran en estibas directas. Solamente se pueden utilizar con medios unitarizadores que posean botellas de 1 L.	1	0	
19		Se cumple con la disposición de estantes respecto a la nave.	0.5	0	
20		Se cumple con el ancho de pasillos en correspondencia con equipos de manipulación.	0.5	0	
21		Se cumple con la disposición de pasillos de trabajo respecto a la nave.	0.5	0	

Figure 2: Aspect use of space in the checklist

No.		Aspectos a evaluar	Calificación a Obtener	Calificación del Almacén	Observaciones
		Organización del almacén.	**20**	**12.5**	
22	Φ	Existe una correcta rotación de los productos.	0.5	0.5	
23	Φ	Las estibas y productos no tienen peligro de derrumbe.	0.5	0.5	
24	Φ	Está señalizada la entrada del almacén, el horario de atención al cliente.	0.5	0.5	
25	Φ	Se refleja en la entrada del almacén, la relación de los cargos con acceso al mismo.	0.5	0.5	
26	Φ	Está señalizada el área de recepción de la mercancía.	0.5	0.5	
27	Φ	Está señalizada el área de despacho de la mercancía.	0.5	0.5	
28	Φ	Es eficiente el método de control de existencia.	0.5	0.5	
29	Φ	Los pasillos y puertas de acceso al almacén están libres de productos u objetos que obstaculicen o entorpezcan el paso de los equipos de manipulación y el personal.	0.5	0.5	
30	Φ	Se observan productos bloqueados en el almacén.	1.5	0	
31	Φ	Se observan productos directamente sobre el piso.	0.5	0.5	
32	Φ	Dispone de facilidades constructivas para la recepción y despacho.	1	0	
33	Φ	Existen procedimientos para disminuir manipulación.	0.5	0.5	
34	Φ	Posee el expediente logístico (EXPELOG) actualizado y en buen estado de conservación	0.5	0.5	
35	Φ	Existe la información básica sobre el almacén.	0.5	0.5	
36	Φ	Existe la distribución en planta potencial.	0.5	0.5	
37	Φ	Existen los parámetros técnicos del almacén.	0.5	0.5	
38	Φ	Existe el estado constructivo del almacén.	0.5	0.5	
39	Φ	Existe el sistema de iluminación.	0.5	0.5	

Figure 3: Aspect warehouse organization in the checklist

No.		Aspectos a evaluar	Calificación a Obtener	Calificación del Almacén	Observaciones
		Organización del almacén.	**20**	**12.5**	
40	Φ	Existe un sistema de ventilación.	0.5	0.5	
41	Φ	Existe el inventario de los equipos de manipulación e izaje.	0.5	0.5	
42	Φ	Están los documentos normativos vigentes.	0.5	0.5	
43	Φ	Está definido el sistema de seguridad y protección.	0.5	0.5	
44	Φ	Está definida área de reparación de los medios unitarizadores.	1	0	
45	Φ	Están los esquemas de carga para cada producto.	0.5	0.5	
46		Tiene todos los productos unitarizados que así lo requieran, en la misma cantidad y forma.	0.5	0.5	
47		Mantener controlada la temperatura, no puede ser menos de 0 y mayor de 50.	0.5	0.5	
48		El almacenamiento del ron se realiza por producciones y surtidos.	0.5	0.5	
49		Tienen los lotes un identificador en el pasillo principal.	1.5	0	
50		Personal con nivel requerido para el desempeño de sus funciones. (Trabajadores capacitados en logística 80%)	2.5	0	El personal no está capacitado
51		Cumple la Resolución 47/2020 sobre expediente logístico. (EXPELOG)	0.5	0.5	

Figure 4: Aspect warehouse organization in the checklist

No.		Aspectos a evaluar	Calificación a Obtener	Calificación del Almacén	Observaciones
		Equipos			
&		Los equipos del piso tecnológico están conectado por red o WiFi en el almacén.		no	
&		Hay interacción hombre-máquina en las actividades automáticas o semiautomáticas del almacén.		si	
&		Los medios informáticos están conectados a los equipos del piso tecnológico.		no	
&		Se realizan análisis de datos o minerías de datos con los resultados obtenidos.		no	
&		Existen tareas automatizadas en el almacén		no	
&		El almacén está conectado a la red informática de la fábrica o la nube de la empresa.		no	
&		Los trabajadores del almacén están capacitados para trabajar con equipos automáticos.		no	

Figure 5: Aspect equipment in the checklist

A series of measures is recommended according to the results implementation plan, which are seen in Figure 6.

Deficiency	Measure	Responsible	Participants	Compliance Date
The height is wasted.	Substitute the transportes.	Managing	Factory Rum	long term
It cannot habitually be carried out a correct cleaning of the local.	Elaborate a plan of cleaning. Control by means of the evaluation of the individual acting of the executioners.	Boss of the warehouse	Worker of Cleaning	Immediate
A faulty artificial illumination exists.	Substitute the faulty stars and to place those that lack	Maintenance boss	Electrician	Immediate
Faulty ventilation.	Place extractors of air.	Managing	Factory Rum	long term
Horizontal marks don't exist.	Make the marks with painting of the color and the appropriate quality.	Boss of the warehouse	Worker of maintenance	Immediate
The personnel is not qualified in logistics of warehouses	Qualify the personnel in logistics of warehouses.	Specialist in Administration of human resources	Boss of the warehouse	Immediate
Not defined the area of repair of the means	Define and to signal the area of repair of the means	Boss of the warehouse	Worker of maintenance	Immediate
The access to the warehouse requires to be repaired	Negotiate with organizations of the territory the repair	Commercial boss	Hired	Medium term
It lacks of the fumigation registration	Make a card for this end	Boss of the warehouse	Boss of the warehouse	Immediate
It is insufficient the quantity of extinguishers in correspondence with the area to protect.	Locate the necessary quantity of extinguishers. Qualify the personnel on their use.	Specialist in Administration of human resources	Boss of the warehouse	Immediate
The personnel doesn't possess the protection means and necessary security.	To give the personnel all the protection means and security required for the execution of the tasks.	Specialist in Administration of human resources	Specialist in Administration of human resources	Immediate

Figure 6: Implementation Plan

The analysis of the consensus index among the experts is higher than 80%, which is why it is considered acceptable. The analysis of the central tendency statistics shows a behavior between adequate and very adequate. It is concluded that the proposed measures are adequate. Following what is proposed by the methodology, the checklist for the second level of categorization is applied, reaching a score of 88.20 points. You get a rating of good; although there are measures to be applied. A new distribution in the warehouse floor is proposed, with it the aim is to improve several of the organizational deficiencies found and the rates of use of areas and volumes of the warehouse. The future layout of the plant can be seen in Figure 7.

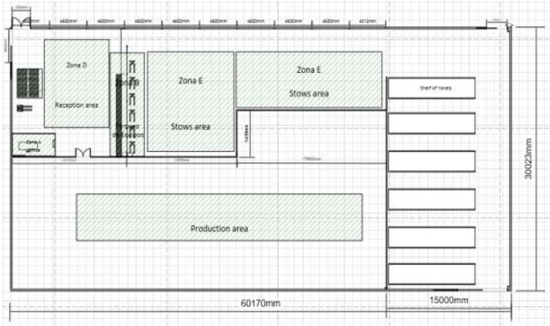

Figure 7: Future plant distribution of the finished products warehouse

5. Conclusions

The proposed procedure constitutes a practical tool aimed at improving the logistics and quality of the warehouse, with a view to increasing its level of certification.

The tools applied as part of the procedure are a combination of qualitative and quantitative methods. A practical contribution of the application of the elaborated checklists show the improvement in the warehouse.

The proposed procedure constitutes a closed cycle with regeneration designed for improvement. It does not end with preparing and obtaining categorization; prepares the factory to achieve systematic adaptation to changes in the environment.

References

[1] MINCIN, M.d.C.I., Resolución 153/07. Procedimiento para la implementación del Expediente Logístico de Almacenes y la Categorización de los Almacenes, in 46, MINCIN, Editor. 2007, Gaceta Oficial Extraodinaria: Cuba.

[2] MINCIN, Resolución 47/2020 Reglamento de la logística de almacenes para las entidades que operan en la economía nacional. 2020, Gaceta Oficial de la República de Cuba: La Habana.

[3] MINCIN, Resolución 64/2020 Creacion de la Comisión Nacional de Expertos de Logística de Almacenes. 2020, Gaceta Oficial de la República de Cuba: La Habana.

[4] Glistau, E., Trojahn, S. and Schenk, M. The Dissertation: Way and Aim. in 11th International Doctoral Students Workshop on Logistics. 2018. Magdeburgo: Institute of Logistics and Material Handling Systems.

[5] Acevedo-Suárez, J.A.G.-A., M, La logística moderna en la empresa., ed. F. Varela. 2010: https://scholar.google.es/scholar/Aceved o-

Suárez/Gómez-Acosta/La-logísticamoderna-en-la-empresa/.
[6] Cespón-Castro, D.R., Manual para estudiantes de la especialidad de Ingeniería Industrial. 2013, Universidad Tecnológica Centroamericana de Honduras: https://scholar.google.es/scholar/CespónCastro/Manual-para-estudiantes-de-laespecialidad-de-Ingeniería-Industrial.
[7] Viu Roig, M., Logística y cadena de suministro en la nueva era digital. Oikonomics Revista de economía, empresa y sociedad, 2018. 9.
[8] Lopes-Martínez, I., et al., Diseño de una metodología para la estandarización de los sistemas de codificación y clasificación de productos en empresas cubanas, 2019. Cuadernos Latinoamericanos de Administración, 2019. 16(28): p. 22.
[9] Calzado-Girón, D., La gestión logística de almacenes en el desarrollo de los operadores logísticos. Ciencias Holguin, 2020. 26.
[10] Ashok-Kumar, L.C.C., Col M.P. Vishal Marwaha, Col. Mukti Sharma,Maj Gen. Brig Manu Arora Improving medical stores management through automation and effective communication, in Elsevier. 2015, https://scholar.google.es/scholar?lookup=0&q=Improving+medical+stores+management+through+automation+and+effective+communication.
[11] Glistau, E. and Coello Machado, N.I.. Logistics concepts and logistics 4.0. Advanced Logistic Systems, 2018. 12: p. 10.
[12] Glistau, E. and N.I. Coello Machado, Logistics 4.0 – basics, ideas and useful methods. 2019. microCAD 2019, Miskolc
[13] Zakoldaev, D.A., et al., Industry 4.0 vs Industry 3.0: the role of personnel in production, in IOP Conference. 2020, IOP Publishing.
[14] Khan, A., J.-F. Brethé, and F. Guérin. An Autonomous Solution for for Warehouse Palletization. In 12th International Doctoral Students Whorkshop on Logistics. 2019. Magdeburg.
[15] Valencia-Granados, J.A., Metodología de diagnóstico logístico de almacenes y centros de distribución. Realidad y Reflexión, 2019. 49.
[16] DNV.GL, Care For Food Safety on the Road, D.N. Veritas, Editor. 2019, BUSINESS ASSURANCE: Høvik, Noruega.

Route planning in matrix production

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1. Introduction

Due to the rapidly changing customer demands, the life cycle of the products is shortened, diversity is increased while the number of products per model is reduced [1], so there is a need to constantly work on the product's innovation and the production-related technologies.
Not only the product itself needs to be renewed, but also flexible, and optimized production technology needs to be developed according to changing customer needs, since a very large number of product variants are produced, these may all require individual setup, identification, tracking and different manufacturing operations [2,3].

Due to the diversification mentioned above, there is a need for an innovative and scalable production system that can handle the rapidly changing needs and uncertainties. A high degree of flexibility associated with high output performance and scalability is also essential [4].

All of this can be accomplished through digitization and networking for an Industry 4.0 company [5]. The necessary simulations and rapid prototype production (e.g., additive production) shorten development and time to market [6]. Fast and flexible production lines always produce as much and as the customer wants. The production data is available immediately, thus the management decisions result high quality and high efficiency. The machines can be connected to an extensive, interconnected network. Thanks to the advanced architecture and control, the machinery can be flexibly and quickly converted if production requires so.

The effect of the Fourth Industrial Revolution is most felt today in the automotive industry, where the growing number of product variants and the constant change in customer demands needs continuous innovation [7]. Customer expectations are differentiating, increasingly heterogeneous customer needs, and the increasing complexity of requirements are typical. As model cycles shorten, the number of models in the product portfolio increases. The number of pieces produced per model shows a decreasing trend. The rising costs for research and development (R&D) and marketing increase the unit price, creating additional price pressure. The dynamic market trends and new technologies require more modular production and supply concepts. High flexibility is needed regarding the volume and technology solutions.

The implementation requires end-to-end data integration in the supply chain [8], automated material flow, and real-time communication. All this requires the development and implementation of new production structures and solutions [9]. One such new solution is matrix production.

The task of the production logistics is to move the workpieces between the workstations within the plant, as well as to supply the workstations with the materials, raw materials, parts, etc. necessary for the given production task. Many material handling tasks occur simultaneously in the production space. In the following, we deal with matrix production, material handling between workstations during production, and the route planning problems that occur in connection with it. We are looking for a routing algorithm that can be used to efficiently move workpieces, as well as how much AGV is needed to perform these material handling tasks.

2. Matrix production

The factory of the future requires a reliable, easy-to-change, flexible production system. Modular manufacturing involves several changes in design, system, and processes [10], but it usually means that manufacturing must be divided into separate cells instead of a continuous line. Manufacturing and assembling the modules at separate stations allows for greater flexibility in the overall output, including changing product options or changing demand. The intelligent matrix production provides a solution to these.

Main features of matrix production [11]:

- Scalable, according to the diversity of the products of tomorrow.
- Variable total capacity by using a modular production area.
- AGV (Automated Guided Vehicles): autonomous vehicles support the processes.
- Freely programmable logistics by connect processes and AGVs.
- High availability through standardized equipment, with the help of production cells modularly assembled for different processes.

One of the most significant advantages of matrix production is the modularity: high availability through standardized equipment; scalability of the total capacity: the size of the system can be expanded modularly, scalability can be implemented according to different variants; the flexibility is related to the types, which is part of the base concept; the scalability of the product mix, which allows to compensate for fluctuations in demand; and that the integration of new products is simple and low-risk [12].

When the products to be manufactured are changed, the production cells automatically switch to the new tasks. The transformation of the cell takes place in parallel with the production in the other cells. After the transformation, the new unit will be manufactured. During testing and maintenance, cell production tasks can be transferred to other cells.

3. Model factory

Through the example of a model factory, we show how to ensure flexibility and a high degree of efficiency with the help of modern, automated machine tools, flexible assembly stations, and autonomous material handling equipment and how to determine the optimal design of the logistics system by exploiting the possibilities provided by simulation.

The optimization process was divided into three main segments (Figure 1), these are the determination of the optimal production sequence, the optimal layout, and the optimal route. The bottleneck is the runtime environment (hardware) and the time [13].
After presenting the model factory, we discuss the possibilities of determining the optimal route in more detail.

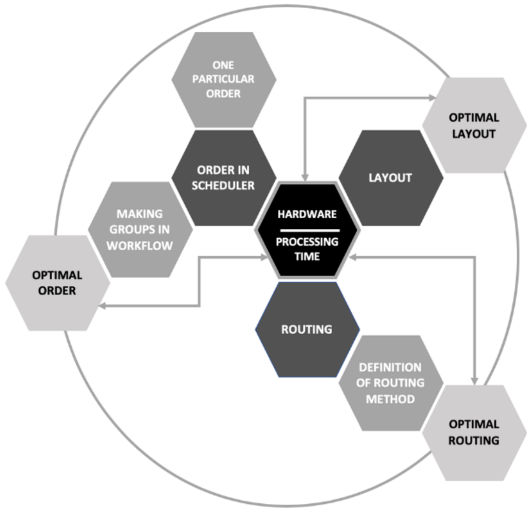

Figure 1: Parts of the optimization task

The model factory has one bidirectional entrance (ENTRANCE), one exit (EXIT) and one AGV container (AGV-POOL), one parts warehouse (WAREHOUSE), one tool warehouse (TOOL STORE), which are located at predefined locations (Figure 2).

In the model factory, there are 12 (3x4) production cells, their position is fixed. The cells are directed, they have an entrance and an exit. There is also an input and an output waiting area in the cells, with the work area located between the two. The AGV does not start from the output location until it can reserve the path to the input cell waiting location.

Cell location 12 is denoted by the capital letters of the alphabet (A-L). The manufacturing process consists of a maximum of 8 operations (a, b,…, h), of which any operation can be omitted.

In the model factory, the products to be manufactured is generated randomly, it is not modified, grouped, or rearranged later, currently we are not optimizing in this regard.
In the present model factory, no failures are expected for either the AGVs or the production cells.
We focus on material handling tasks related to workpieces in the manufacturing process below.

Figure 2: Visualization of the model factory

When determining the route, the following constraints and neglects are applied:

- The number of AGVs is not limited (only indirectly due to route requests), so in this example, it is not worthwhile to deal with the operating time and charging time of AGVs either.
- AGVs are all the same, they cannot reverse, they have two constant speeds (on a straight road, in a bend).
- Routes between and around cells are single-lane, rounds are not curved.
- Movements within WAREHOUSE, AGV-POOL, TOOL STORE are not examined, only an average time spent there is considered.
- An operation has one AGV and one AGV performs only one operation at a time (no sharing of jobs).
- If an AGV wants to change its position, it asks for route permission, which determines the exact trajectory of the relocation. Multiple AGVs moving in one direction may be present on one section (branch to branch), keeping the appropriate distance.
- We do not allow two-way traffic on the reserved route.

During the optimization, various objective functions can be specified, such as:

- minimizing the distance traveled,
- minimizing the time required for production,
- maximizing capacity utilization,
- reduction of downtime,
- minimizing the energy consumption,
- minimizing the costs.

3.1. Software

The digital twin of the production process is a software created by us, suitable for scheduling production tasks and assigning material handling tasks. The software consists of three main components, these are:
the simulator - which visually shows the operation of the plant in real-time for a given layout; the scheduler – which performs the production in the given order for the given layout, the layout variator - which sends the scheduler through all possible layouts.

Input parameters:

- list to be manufactured denoted with letters (abefgh), one product per line,
- Location of ENTRANCE, EXIT, AGV, WAREHOUSE, TOOLS points, cells, nodes on the map
- working time in each cell, according to the manufacturing process there
- AGV speed on straight sections, and in bends

Using simulation of the manufacturing process in any moment of time or duration can be viewed, in fact, the scheduler's output is visualized.
The simulation shows the elapsed time since the start of the production, the number of workpieces completed, the number of tasks performed in each cell and the utilization of the cell.

The scheduler's output is the registration of the run information generated during the production in the given order on the time axis t, a "what happened" file is created, later the simulator will use this file. An AGV log is created which shows when an AGV did what. AGVs can have the following statuses: not working, loading, unloading, waiting for production, waiting to proceed, waiting for route. The cell production log (production start, end of production, parts warehouse filling, idle) can be used to check the utilization.

The variator records the following aggregate data for the production with the best N time results: total time (ENTRANCE (0) .. EXIT (n)), average EXIT time, variance, maximum AGV requirement, AGV utilization broken down for each status, utilization data of cells, average preparation time of one product, variance. If the worst of the top N time is known, then if a production reaches this time before it is completed, the scheduler will stop and give a "not worth counting" status in response.

3.2. Defining routes

As shown in Figure 2, each node, exit, and entrance have a unique identification number. All road sections shown in the figure are single-lane. At the beginning of the production, all AGVs are in the AGV-POOL, here we do not limit the number of AGVs. The AGVs then go to ENTRANCE to pick up the workpieces and then transport them to the cells serving the processes according to the workpiece production process list (e.g., to ABKL cells for the abgh production list). After the last manufacturing process, the finished product must be delivered to EXIT and then AGV goes to AGV-POOL. A maximum of 6-6 vehicles can be present at the ENTRANCE and EXIT locations at the same time for loading and unloading, thus representing the limited space available there.

The cells can have two types of orientation, either each cell can be traversed from left to right or the entrance is on the left side of the cells in the odd row, while the entrance is on the right side of the cells in the even row. An AGV must request a route permission if it wants to change its position (e.g., go from cell A to cell C). This prevents vehicles traveling opposite each other between two adjacent junctions, resulting in unexpected congestion. When requesting a route, the AGV can only receive a route if the destination can receive it (e.g., the production cell is empty, or the input buffer is free). From the possible routes between the current position and the destination, the shortest possible one is chosen, on the route of which no other AGV has yet been authorized to travel in the opposite direction. We examine the shortest 32 routes between the two points. If multiple paths of equal length are available, we select them using the modulo residual classes method (the time elapsed since the start of production is divided by the number of good paths and then the sequence number corresponding to the remainder is selected), thus, it can be solved that the algorithm does not always choose the first good solution and load the nodes unevenly. However, since we do not use a random number generator, we always get exactly the same result, log files, for any number of runs (in the case of a production task with the same parameters). The selected route is then reserved (red arrows in the figure), and we will not allow oncoming traffic in any part of the route until this AGV is passed. With all these restrictions, it is possible to avoid unnecessary waiting, and to avoid congestion in front of the input buffer of a cell, which would obstruct the traffic, and to keep the material handling path as short as possible.

We have generated a manufacturing process list for 3,000 products. Each manufacturing process (a..h) has the following probabilities for each product: a: 71.17%, b: 80.83%, c: 39.80%, d: 70.50%, e: 94.73%, f: 24.80%, g: 84.70%, h: 100.00%. From now on, we always work with this list.

We examined a randomly selected layout in terms of how the waiting, movement and production times change as a function of the number of AGVs.

Production time of the xth workpiece:

$$t_x = \sum_{i=0}^{m+2} \left(t_{Pr,x}^{i} + t_{WP,x}^{i} + \sum_{j=0}^{k_i} t_{WR_j,x}^{i,i+1} + t_{M,x}^{i,i+1} \right) \quad (1)$$

where

- m is the number of items in the production process list of the xth workpiece,
- $t_{Pr,x}^{i}$ is the working time at the i-th point,
- $t_{WP,x}^{i}$ is the waiting time for the route at the i-th point,
- $t_{WR_j,x}^{i,i+1}$ are the elements of the waiting times for the journey at the i-th point and on the route to the i + 1-th point,
- $t_{M,x}^{i,i+1}$ is the material movement time between the i-th and i + 1-th points.
- The 0. point is the AGV-POOL, the 1. is the ENTRANCE, the m+2. is the EXIT, the m+3. is the AGV-POOL.
- The loading and unloading times were defined as 120s, while the technical time to be spent in AGV-POOL was defined as 60s (t_{Pr}^{1}, t_{Pr}^{m+2}, t_{Pr}^{0})

Table 2: Manufacturing process characteristics for different numbers of AGVs

AVG	PROD.TIME (h)	WORKCNT (piece)	WORKSTEP (h)	MOVING (h)	WAITING FOR PATH (h)	WAITING FOR ROAD (h)	FINISHED (h)	MOVING TIME (h)	WORKING TIME (h)	WAITING TIME (h)
8	81,57	375,00	67,11	9,35	0,36	4,59	0,16	74,79	536,90	39,61
9	73,53	333,30	59,66	8,33	0,52	4,86	0,17	74,93	536,90	48,41
10	67,22	300,00	53,69	7,51	0,70	5,17	0,15	75,14	536,90	58,66
11	62,26	272,70	48,81	6,85	0,99	5,46	0,15	75,39	536,90	70,95
12	58,26	250,00	44,74	6,31	1,38	5,69	0,13	75,67	536,90	84,92
13	55,25	230,80	41,30	5,85	2,02	5,97	0,12	76,03	536,90	103,80
14	52,74	214,30	38,35	5,45	2,81	6,03	0,09	76,35	536,90	123,83
15	50,96	200,00	35,79	5,14	3,86	6,08	0,09	77,03	536,90	149,11
16	49,93	187,50	33,56	4,86	5,42	5,99	0,10	77,81	536,90	182,54
17	49,32	176,50	31,58	4,64	7,23	5,78	0,08	78,86	536,90	221,30
18	49,00	166,70	29,83	4,45	9,09	5,55	0,08	80,16	536,90	263,59
19	49,10	157,90	28,26	4,30	11,27	5,19	0,08	81,63	536,90	312,68
20	48,90	150,00	26,85	4,15	12,85	4,95	0,10	82,96	536,90	356,06
21	49,18	142,90	25,57	4,02	14,81	4,68	0,11	84,34	536,90	409,26
22	48,84	136,40	24,40	3,88	15,99	4,44	0,12	85,36	536,90	449,55
23	49,06	130,40	23,34	3,77	17,59	4,23	0,13	86,62	536,90	501,99
24	49,08	125,00	22,37	3,65	18,88	4,03	0,15	87,59	536,90	549,79
25	48,76	120,00	21,48	3,51	19,75	3,87	0,14	87,77	536,90	590,71
26	49,08	115,40	20,65	3,40	21,13	3,74	0,16	88,49	536,90	646,74
27	48,78	111,10	19,89	3,29	21,74	3,66	0,20	88,83	536,90	685,74
28	48,81	107,10	19,18	3,17	22,75	3,55	0,17	88,89	536,90	736,36
29	48,87	103,40	18,51	3,07	23,73	3,39	0,17	88,96	536,90	786,53
30	49,01	100,00	17,90	2,97	24,64	3,29	0,21	89,22	536,90	837,89

The columns in Table 1 are as follows: PROD.TIME: time required to produce 3000 products, WORKCNT: average number of products deliver by the AGV during the process, WORKSTEP: average of the sum of loading and unloading times, technical time in AGV-POOL, time spent in production cells per AGV, MOVING: average of material handling time total per AGV, WAITING FOR PATH: average of total route waiting time per AGV, WAITING FOR ROAD: average of road waiting time total per truck, MOVING TIME: total time of AGVs with material handling, WORKING TIME: total time spent by AGVs on work, WAITING TIME: total time spent by AGVs with waiting.

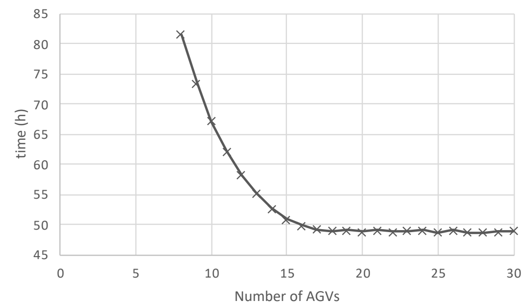

Figure 3: Total production time required as a function of quantity of AGVs

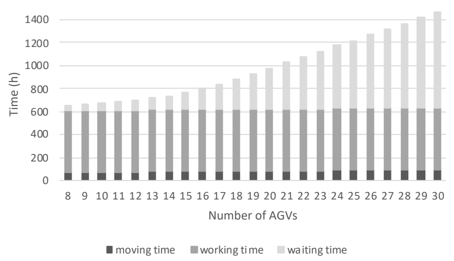

Figure 4: Total time spent on material handling, waiting as a function of the amount of AGVs

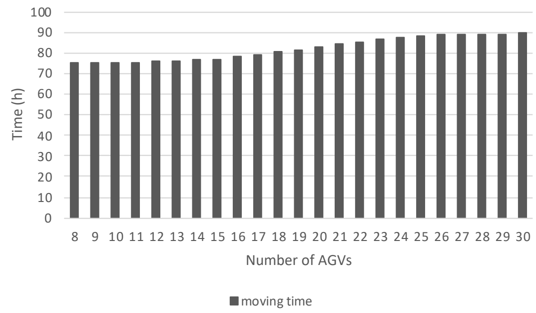

Figure 5: Total time spent on material handling as a function of the amount of AGVs

The Figure 3-5 show the results. It seems that above 17 AGVs there is no longer a significant improvement in terms of total time, at the same time the waiting times of each AGV are significantly increasing. The time spent on material handling increases with the increase in the number of AGVs, the main reason being that the presence of larger amounts of AGVs results in longer movement paths in several cases.

4. Comparison with linear production line

Applying the production times per cell according to Figure 2 to the production order abcdefgh gives 525s as a result. AGV-POOL, ENTRANCE, EXIT times should each be 10s. The time between two different "stations" in a linear production line should be 4s and the material handling time between the entrance station 1 and the station 8 exit should be 10s. We do not modify the layout of the model factory, we do not change the location of the entrance, exit, AGV storage, we prescribe the "i" process for each cell of the third row, as these cells will not be involved in production. All of these results in 8-8 workstations in both matrix and conventional production, but we can be sure that by modifying the exits, we can obtain more favorable time data for matrix fabrication.

In the case of matrix production, a total time of 2990.1 minutes is obtained during the running of the simulation. To produce the same 3000 products for the linear production line, the calculation procedure is as follows:

- the production time of the first product is 10s + 66s * 8 + 4s * 7 + 10s, i.e., 576s,
- then another product is made after every 66s,
- total time required for production: 576s + 66s * 2999 = 198510s, i.e., 3308.5 minutes.

The time required for matrix production is 9.6% less even with a poor layout.

5. Further development

Tasks for the following research period are:

- the introduction of raw material supply to cells,
- find an optimal parts replenishment algorithm based on the parts depletion log and the idle periods (which is the least disruptive to the production),
- implement the possibility of the retooling of the cells,
- implement the possibility of failures in the model (cell, AGV),
- change the production order of products,
- layout optimization.

6. Summary

With the real-time availability of information on the production at companies using Industry 4.0 technology, when the current state of the production process operations, material handling equipment and resources is constantly known, the problems and capacity shortages can be solved immediately, which allows the production and logistics system operation to be optimal. In this study, we have shown, through the example of a matrix-manufactured model plant, how to determine the optimal material handling path and how the production time changes when we modify the number of AGVs used.

References

[1] Koren Y . (2010): The Global Manufacturing Revolution: Product-Process- Business Integration and Reconfigurable Systems. Hoboken: John Wiley & Sons

[2] KPMG (2016): The factory of the future, https://assets.kpmg.com/content/dam/kpmg/es/pdf/2017/06/the- factory-of-the-future.pdf, Germany

[3] Zhou, Q.; Souben, P.; Besant, C.B. An information management system for production planning in virtual enterprises. Computers and Industrial Engineering 1998, 5:153–156. doi:10.1016/S0360-8352(98)00044-8.

[4] Piller, F.T. (2006): Mass Customization. Ein wettbewerbsstrategisches Konzept im informationszeitalter (Mass Customization. A competition-strategic conzept in information era). 4rd ed. Wiesbaden: Gabler

[5] Watson R. Jump Starting Digital Transformation in Manufacturing. https://www.manufacturingglobal.com

[6] Bohács, G., Kovács, G., Rinkács, A. Production Logistics Simulation Supported by Process Description Languages.Management and Production Engineering Review2016, 7(1):13-20

[7] Svéhlik, Cs. (2005): Paradigmaváltás az autóiparban: A technika-központúságtól a márka- és vevőközpontúságig. In: Marketingoktatás és kutatás a változó európai unióban. Széchenyi István Egyetem: Győr. ISBN: 963 717 525 3

[8] Bányai, T. (2018): Real-time decision making in first mile and last mile logistics: How smart scheduling affects energy efficiency of hyperconnected supply chain solutions. Energies 11: 7 Paper: 1833

[9] Baldea, M.; Edgar, T.F.; Stanley, B.L.; Kiss, A.A. Modular manufacturing processes: Status, challenges, and opportunities. Aiche Journal 2017, 63:4262–4272. doi:10.1002/aic.15872.

[10] Fang, C.C.; Lai, M.H.; Huang, Y.S. Production planning of new and remanufacturing products in hybrid production systems. Computers and Industrial Engineering 2017,

[11] KUKA AG (2016): Industrie 4.0: Matrix Produktion. https://www.kuka.com/

[12] KUKA AG (2016): Matrix production: an example for Industrie 4.0, https://www.kuka.com/en-ch/industries/solutions-database/2016/10/industry-4-0--matrix-production

[13] Hardai, I.; Illés, B.; Bányai, Á. (2019): Efficiency improvement of manufacturing and logistic processes in industry 4.0 environment, 12th International Doctoral Students Workshop on Logistics, Otto-von-Guericke-Universität Magdeburg, Germany

Intelligent solutions for industrial automation

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Abstract
By combining digital, physical and virtual realms, cutting edge technologies are redefining how products are designed and manufactured. Digital engineering is leading to the creation of intelligent products, services and next-generation technology approaches that add value to the end user. Never before in the history of mankind has life and its quality, and not only in the most developed countries, changed so quickly. Every day there are more and more new scientific and engineering developments and, accordingly, new areas of their application. Most of these new applications arise from growing computing power, fast connections, cheap storage, and high performance sensors. According to Gartner, 20.4 billion connected devices are likely to be in use globally in 2021. And this applies to all industries without exception, including the automotive industry, industrial production, high technology, energy, utilities and much more.

1. Introduction
Features of the current stage of development of mechanical engineering are characterized by the significant distribution and use of multifunctional CNC machines. The use of this type of equipment can significantly increase processing productivity and improve the quality of manufactured parts [1, 2, 3]. In this regard, systems for monitoring the operation of the company's machine park have become very popular. The scheme of operation of any industrial equipment monitoring system implies the transfer of data from machine tools via a local (less often wireless) network to a server with subsequent processing and visualization in client applications. In this case, we are not talking about equipment management, but only about obtaining the data necessary for the subsequent analysis of the efficiency of its operation [4]. There are two main options for implementing the MDC system (Machine Data Collection): hardware and software. The first on the market were systems with hardware data collection technology. In the 1990s, CNC machine systems were not so smart and in most cases did not allow openly exchanging information with external systems, with the exception of the functionality of receiving and transmitting a control program. An obvious plus of the hardware implementation is the ability to collect discrete signals from almost any equipment: the monitoring system will be able to combine into a single information space not only modern CNC machines, but also universal machines, welding installations, heat treatment furnaces, etc. The disadvantage of such a solution is that an enterprise needs to purchase not only software, but also hardware products, which makes the system more expensive [5]. Also, connection of new machines under warranty to electro automatic equipment may require agreement with the manufacturer or supplier. The idea of the system with software technology for data collection is to connect a network cable to the appropriate connector of the CNC rack and set the IP address of the machine in the application settings. However, in the implementation of software technology in practice, there are many obstacles. First, not all CNCs are equipped with a network card and an Ethernet port. Secondly, only some of them allow free exchange of system data [6]. The biggest problem is that usually the machine park of the enterprise consists of machines of various types and brands. Thus, some of the existing equipment does not support

software monitoring or does not have a controller at all.

In the future, it will be the software implementation of data collection that will be used much more widely. The coming decades will see further rapid development of the Internet: Internet technologies will penetrate into many areas of activity, including industrial production. The traditional gap between managers and production personnel will be blurred by new components of control systems and equipment connected to the Internet of Things (IoT) [7, 8, 9]. Before Industry 4.0 really takes off, the manufacturing infrastructure needs to be in place. Every device on the shop floor will require a reliable, active network connection. The introduction of "smart technologies" in the shops of manufacturing enterprises will increase production efficiency and reduce overall costs. Implementing a smarter production environment is important today.

The research is devoted to the development of the software interface of application for the remote access to CNC machines. This technological solution will allow you to remotely control the workshop CNC machines, as well as directly configure them for certain actions without the worker's contact with the machine.

2. Experimental part

Modern self-adjusting machines "understand" the current position of all executive bodies during processing, compare them with the values specified in the control program, and, if necessary, correct them. Also, the principles of operation of the CNC systems of a milling machine and a lathe are identical: the microcontroller issues control signals to the drives of the spindle and the tool portal, the inclusion of peripheral devices (lubrication, coolant supply, aspiration). In this case, the machine must know where the tool is at the current moment. The feedback of the machine is responsible for this function.

The idea of developing the application is based on the fact that each CNC machine has its own IP address. The connection to the machines is done using an SSH key. You need to share your SSH key in order to connect the CNC machine and the remote computer. The SSH key is split into two parts. One part is called private and should always be stored only on the user's computer. The second part of the key is called public and this part needs to be copied to the CNC machine. When connected to the machine, the SSH key compares the public part that was sent to the machine with the private part that is stored on the remote computer. If the parts of the key match, then we get access to the CNC machine. Any number of SSH keys can be created on the user's computer. That is, you can use one SSH key to access hundreds of CNC machines or create a separate key for each machine.

For the convenience of users, it was decided to connect a database to store MongoDB user accounts. The database stores not only information about the user's data, but also his last actions. For example, machines that he can manipulate. The Apollo GraphQL Client language is used to query the database. Thus, the graphical interface with which the user is working is not loaded. For convenient use of the application, the Redux library was connected. It is one simple store in which all actions on the machines are indicated.

The software interface supports any CNC systems. The only condition is the ability to connect the controller to a local area network Ethernet (directly or through a converter if the controller is equipped with an RS232 / 485 or USB connector). To connect to the system, no modification of the machine controller or installation of additional software or hardware is required, which may result in the loss of the hardware manufacturer's warranty.

The system already includes pre-configured templates for controllers of the most popular CNC systems: FANUC, HEIDENHAIN, HAAS, Siemens, Mitsubishi, WiMAX (Hurco), BaltSystem, etc.

During operation, the system can have three states:

- readiness state - the machine is connected to the power grid and is ready to perform tasks;
- processing state - the machine is processing the workpiece;
- pause - the - pause button is pressed;
- the system pauses the machine until further user commands are entered.
-

The main operating interface of the system is shown in Figure 1. It consists of the following components: Title bar, Toolbar, Menu bar, Advanced toolbar, Main window, Status bar and four functional areas.

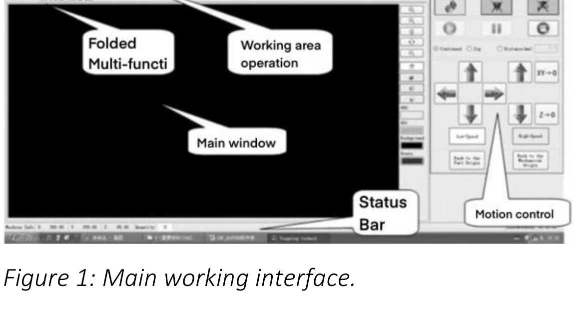

Figure 1: Main working interface.

The first functional area shows information about the job, progress, file size and percentage of completion to the end of processing. The second functional area shows coordinate position information, spindle speed, etc. The third functional area shows movement control, automatic or manual mode, etc. The fourth functional area has a main file viewer, system log, I / O and preview of some toolpaths and etc.
If the system recognizes the file, then the working window will display the cutting tool operation schedule (Figure 2). Then we press the run button, the machine starts its work.

Figure 2: Example of a cutter schedule

3. Results

The general controllability of a production unit based on CNC machines depends on the availability of local management links - CNC devices, means of automating auxiliary operations, and means of operational diagnostics. Accurate control of the parameters for performing technological operations allows you to constantly improve the technologies for manufacturing products and methods of processing parts on specific equipment. Additional value is added to the information system by data obtained directly from the CNC, as well as from auxiliary automation equipment, such as measuring equipment, diagnostic devices, vibration control devices. The result of "control by technological parameters" is an increase in the overall efficiency of the equipment - in terms of load, productivity and product quality.
Relying on detailed operational control of technical and technological parameters directly in the process of processing parts, using data from current diagnostic control, including with the help of vibration diagnostics, such systems help to eliminate the risk of failure of machine tools and their most critical units, and also provide information, allowing for optimal planning of preventive maintenance.
The capacity of the machine park is an important factor in the competitiveness of an enterprise and its readiness to fulfill orders that are complex in terms of volume and quality, timing and flexibility of equipment changeover. Expensive equipment will not give the desired effect without high-quality management of the equipment fleet in real time. Implementing the software interface of application for the remote access to CNC machines will provide the deepest visibility to any process from anywhere in the plant.
In future, this software interface of application for the remote access to CNC machines will allow you to remotely control the workshop CNC machines, as well as directly configure them for certain actions without the worker's contact with the machine. Future research directions will be focus on effective remounting CNC machines to provide the maximize signal strength.

4. References

[1] Nallusamy, S. “Enhancement of Productivity and Efficiency of CNC Machines in a Small Scale Industry Using Total Productive Maintenance.” International Journal of Engineering Research in Africa, vol. 25, Trans Tech Publications, Ltd., Aug. 2016, pp. 119–126, doi:10.4028/www.scientific.net/jera.25.119.

[2] Koren, Y. (November 1, 1997). "Control of Machine Tools." ASME. *J. Manuf. Sci. Eng*. November 1997; 119(4B): 749–755, https://doi.org/10.1115/1.2836820.

[3] Martinova, L.I., Martinov, G.M. Prospects for CNC Machine Tools. *Russ. Engin. Res.* **39,** 1080–1083 (2019), https://doi.org/10.3103/S1068798X19120153

[4] Petreshin, D.I.; Suslov, A.G.; Fedonin, O.N. NC machines upgrade and automated system for data collection NC machines functioning. «Science intensive technologies in mechanical engineering», № 4, 2016 p. 135 – 140.

[5] Xu, X.W; Newman, S.T. Making CNC machine tools more open, interoperable and intelligent—a review of the technologies. Computers in Industry Volume 57, Issue 2, February 2006, Pages 141-152, https://doi.org/10.1016/j.compind.2005.06.002

[6] Prathima, B. A.; Sudha, P N.; Suresh, P. M. Shop floor to cloud connect for live monitoring the production data of CNC machines. International Journal of Computer Integrated Manufacturing Volume 33, 2020 - Issue 2, https://doi.org/10.1080/0951192X.2020.1718762.

[7] Zhong, Ray Y.; Xu, Xun; Klotz, Eberhard; Newman, Stephen T. Intelligent Manufacturing in the Context of Industry 4.0: A Review. Engineering Volume 3, Issue 5, October 2017, Pages 616-630, https://doi.org/10.1016/J.ENG.2017.05.015.

[8] Rafael, L. D.; , Jaione, G. E.; Cristina, L.; Ibon, S. L. An Industry 4.0 maturity model for machine tool companies. Technological Forecasting and Social Change, Volume 159, October 2020, p.120-203, https://doi.org/10.1016/j.techfore.2020.120203.

[9] I. R. K. Al-Saedi, F. M. Mohammed and S. S. Obayes, "CNC machine based on embedded wireless and Internet of Things for workshop development," *2017 International Conference on Control, Automation and Diagnosis (ICCAD)*, Hammamet, Tunisia, 2017, pp. 439-444, doi: 10.1109/CADIAG.2017.8075699.

Consumer-friendly charging process based on AI and V2X

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Abstract
Electromobility is currently recognized as one of the key technologies to decarbonize the transport sector [1]. An important component of electromobility is charging at public charging infrastructure [2]. Easy access to public charging stations is a cornerstone for the success of the traffic turnaround in transport [3]. And here is where the problems arise: no overview of the charging options, various operators/ providers, no uniform authentication, tariff, and payment methods, and different prices [4, 3, 2]. Here, consumers lose track of things [4, 3, 2]. We need a consumer-friendly charging infrastructure respectively a charging process, where BEV drivers and potential BEV drivers have an overall overview of the current system regarding to billings, tariffs, prices, etc., and a central point at which BEV drivers have non-discriminatory access to all charging stations. Innovative technologies such as vehicle-to- everything communication (V2X) and artificial intelligence (AI) should in the future be able to optimize and partially automate the current charging process for the BEV driver. Based on these technologies the charging process will be more consumer-friendly. This paper is intended to show the problem of the current charging infrastructure, more specifically said the process from the customer's point of view. It also should show the potential of using innovative technologies such as V2X and AI in the charging process.

1. Introduction

Electromobility is currently recognized as one of the key technologies to decarbonize the transport sector [1]. It could make a significant contribution to reduce emissions and dependence on oil by using energy from renewable sources and to strengthen Germany as an industrial location [5]. Research from BDEW shows three main reasons why people do not want to buy a BEV: high purchase price, limited range, and too few public charging stations [6]. Charging at public charging infrastructure is an important component of electromobility [2]. Besides to the cost of purchasing a BEV and the limited range, easy access to public charging stations is a cornerstone for the success of the traffic turnaround in transport [3]. In this context, public charging of BEVs represents a new, challenging experience for drivers, which is not comparable to current tank operations [3]. Many studies (e. g. EuPD Research (2020), LichtBlick (2020), Prognos (2020)) offering the massive problems around the charging infrastructure [4, 3, 2]. BEV users currently do not have a comprehensive overview of the charging options, the Charge Point Operator (CPO)/ E-Mobility Provider (EMP) and their tariffs, billing, and payment methods, prices, and accesses to different charging stations [2, 4, 3]. Based on this background BEV drivers currently have to download a separate app for each CPO/ EMP or even have to carry around various charging cards and can only compare the prices of charging stations online or on the mobile phone and have to find their way through the jungle of tariffs [3, 4, 2]. And in some cases, users also must register on third-party websites before they can charge [3, 4, 2]. So, users do not have data gathered at one central point. And this is the point where the user or maybe a potential BEV driver loses track of things [7, 8]. The conditions of the current charging infrastructure are one of the biggest obstacles to a green transportation transition [3]. Despite increasing criticism from consumers as well as politicians, CPOs do not change anything [3]. Therefore, we need a consumer-friendly charging infrastructure respectively a charging process, where BEV drivers and potential BEV drivers have an overall overview of the current system regarding to billings, tariffs, prices, etc., and a central point at which BEV drivers have non-discriminatory access to all charging stations. The vision of this paper is to optimize and partially automate the charging process for the BEV driver based on innovative technologies like V2X and AI.

The general objective of this investigation is defined as:
• show the problem of the current charging infrastructure, more specifically said the process from the customer's point of view.
The specific objective of this investigation is defined as:
• show the potential of using innovative technologies such as V2X and AI in the charging process.

2. State of the art

In this chapter, approaches to optimizing the charging process are surveyed. Furthermore, the use of AI and V2X in the charging process is analyzed.

2.1. Current approaches to optimizing the charging process

Today there are many solution approaches which purse the goal to optimize and simplify the actual charging process for the BEV drivers.
Solutions that enable a customer-friendly access to charging stations is bilateral contracts or business and IT platforms (so-called e-roaming platforms) [2]. According to the study "Accompanying and Impact Research on the Electromobility Showcase (BuW)" there are three idealized models of cooperation within e-roaming, like the meshed network, the hub-and-spoke network and the spoke-model interroaming network [9]. Based on Platforms, CPOs make their charging infrastructure available to EMPs [2]. The CPO is the operator of a charging station and is initially responsible for the technical maintenance, installation, power supply and also for access to the charging station [2]. The EMP is responsible for the access, tariff and billings [2]. Here, the driver has access to the charging stations of all CPOs with which their EMP has a contract via an e-roaming platform and have the access to the charging station of their EMP via e. g. charging card or app [2]. This allows an across-operator and cross-provider charging.
Another solution approach related to the difficult access and payment at a charging point is nowadays the so-called Plug & Charge (PnC) by using the ISO 15118 "Road vehicles - Communication interface between vehicle and charging station" [10]. Nowadays one individual charging contract is integrated in the vehicle, which means that only one provider is allowed per vehicle [10] Furthermore, BEV drivers must first find a charging station where a "PnC icon" can be located to use this service [10].
A further approach is based on the blockchain technology. At an approach of the Fraunhofer FIT, public distributed ledger technology (DLT)-system-based platforms replicate the existing functionalities of the e-roaming cooperation model variant, spoke-model interroaming network [11]. Also, startups such as PolyCrypt and Riddle & Code in cooperation with Wien Energie are also using the blockchain technology to simplify the payment at charging stations [12, 13]. Bosch, together with the energy supply company EnBW is also taking advantage of the blockchain technology approach, but in combination with AI [14]. Here, they want to optimize the entire charging process based on software agents [14].
Another solution is Autocharge. It needs an app (Fastend) to be downloaded and an account to be created respectively a registration is needed [15]. This enables automated identification and billing in which the first charging process is scanned and stored [15].
Within this solution approach, it is about barrier-free access and payment to the charging stations [16]. Here, the two companies Wirelane and FEIG ELECTRONIC are are integrating a module at which the BEV driver could pay with NFC-enabled credit or debit card or girocard, smartphone wallets (Google, Samsung, Apple Pay) [16].

2.2. Current applications of AI and V2X in the charging process

NewMotion, in cooperation with other companies, is currently building charging stations that enable V2G and V2X communication [17]. The goal is to enable bi-directional charging, into the public as well as the private power grid, based on cloud-based control [17]. Another solution comes from the Ostschweizer University of Applied Sciences [19]. Here, V2X enables automatic authentication from car and the charging station [18]. In various publications, the topic of AI in the charging process has been related to energy and load management. For example, AI can make predictions about the load profile for optimal use of charging stations, BEV driver behavior for better scheduling, BEV power consumption, short-term BEV charging prediction, BEV charging behavior, and more [19, 20, 21, 22, 23, 24, 25]. Camera-based artificial intelligence parking occupancy detection of BEV parking spaces is also possible [26]. Also, Ford wants to use an algorithm to support the future use of BEV in cities, in which an AI calculates strategically useful locations for charging stations [27].

2.3. Research gap

Based on the previous chapter, the research gap can be defined:

- no comprehensive solution approach that integrates the existing charging stations at one gathered point for the BEV driver

- no approach that integrates a comprehensive overview of the entire network of charging stations
- every BEV driver must sign a contract or has to register
- no combined, comprehensive solution approach with AI and V2X

3. Material and Methods

To charge the BEV, processes must take place on the part of the user. These are described and illustrated below from the point of view of the BEV driver. This follows the solution approach with the integration of the innovative technologies V2X and AI. The approach is described and illustrated.

3.1. Current state

The current state of the charging process is basically differed in:

- with registration/ contract with the EMP/ CPO
- without contract and registration [28, 29, 30, 31]

In principle, the following process steps takes place:

- Authentication and authorization
- Connecting the charging cable
- Starting the charging process
- Ending the charging process [28, 29, 30, 31]

The following Figure 1 illustrates the current above-mentioned two general charging processes.

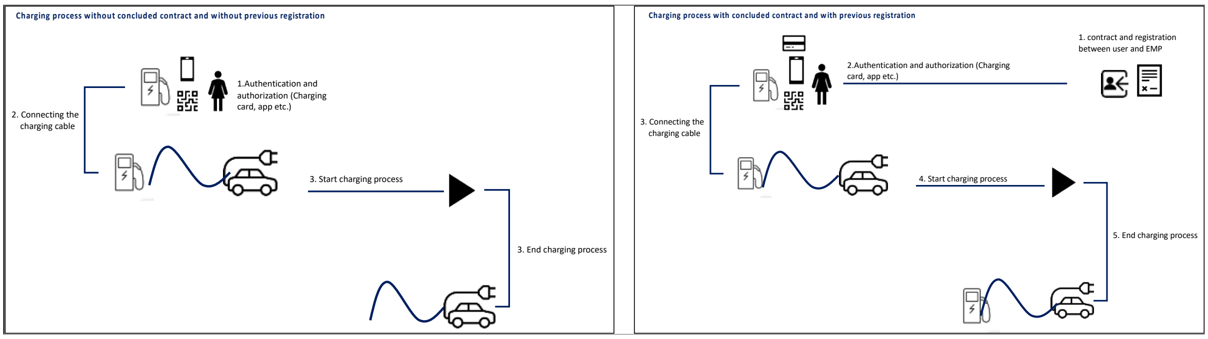

Figure1: Charging process with contract/ registration and without [29, 30]

3.1.1. Process description

In the following, the charging processes are described in more detail.

Authentication and authorization

Access authorization means the activation of the charging station [32]. Only after the identification has been completed the charging process can begin [32]. Within the access systems with registration/ contract or without, different methods can be differentiated. These are shown in the following table 1. By the access systems with registration/ contract the BEV driver must register or contract with an EMP before the process of charging. The access system without registration/ contract is easier. The BEV drivers have only to pay the charging process. The payment methods differ. The payment for registrations/contracts will be executed with the payment method defined in the registration or contract [29, 31]. In the case of access systems without registration/contract, a different payment variant is offered depending on the type of access [29, 31]. Besides it is possible to differentiate between various billing methods (kWh, time based, flat rate, monthly charge, etc.) [2, 4, 3, 31].

Table 1: Brief overview of the methods of the access systems with and without registration / contract [31, 4].

Access systems with registration/ contract	**Access systems without registration/ contract**
Via charging card	Via mobile phone (SMS)
Via app	Web based (QR-Code)
Via plug and Charge	Via NFC credit card
Via mobile phone (phone call / SMS)	Via coin machine
Via Charging Chip	Via offset with parking ticket
…	Via plug and Charge

Connecting the charging cable

Within this process step, the “tank” cap of the BEV is opened so that the car and charging station can be connected [28, 30].

Starting the charging process

If the BEV is connected to the charging station plug, the ends of the plug are automatically locked so that no one can interrupt the charging process without authorization [28, 30].

Ending the charging process

The charging process ends automatically when fully charged or when the desired charge level is reached, in which case the process must be stopped and the driver must log off [28, 30]. The same method must be used to start the session (e. g. app or charging key) [28, 30].

3.2. Solution approach

Due to the research gap (ct. 2.3.) and to create a customer-friendly approach for the charging process, the solution approach takes place. Here, the approach is visualized and described. The solution approach is based on V2X and AI. Here, V2X and AI take on various tasks throughout the entire charging process (from contract to authentication to payment process).

The first task of the AI is to collect data from all charging stations in e. g. Germany (offline and online). Even if new charging stations are built, renewed, or removed.

The following data should be collected:

- locations,
- represented EMP/ CPO
- offered tariffs, prices, and billing methods,
- kinds of charging stations (normal and fast etc.),
- used plugs of the charging station.

This data is then transferred to a so-called AI platform. It is a non-profit self-generating AI platform. Self-generating because it collects its data continuously itself. On this platform, the AI has to collect, analyze, prepare and visualize the data. After this process, the data will be transferred to a special software in the car or to an interface at the navigation system. The unique selling proposition of this platform is that the platform makes contracts with all EMPs/ CPOs offered tariffs. The platform operates as a so-called ePerson. So, the BEV driver needs no longer to register at an EMP/ CPO by himself. The only thing the user must do before he can use this service is to define a payment method and accepting the term of use on the platform or at the software in the car. The concept is like Paypal. It facilitates payments between parties (EMP/ CPO) through online transfers. The AI should also do smart analysis and give BEV users recommendation which tariff is the best for the charging behave (in long term) or gives the BEV driver analysis of its charging behavior over the last month and provides recommendations for action. Furthermore, the AI can determine the best route for a driver, which is based on the charging infrastructure or the drivers preferences. The AI is called "AI as-a-service". It also has an interface to the V2X-Modules. In the process, the two components must communicate before and during the charging process. Here, for example, data is transmitted as to whether a charging station is free or not. The task of the V2X communication is to give the BEV automatic access to the charging station. And enables communication with approaching BEVs that have an intention to charge. Make the access possible, the BEV and charging stations must have the appropriate hardware and software. An On-Board Unit (OBU) and a Road Side Unit (RSU) are required as hardware to establish the connection. The RSU is located at the charging station, whereas the OBU is in the vehicle. These enable communication via the mobile network or WLAN technology. There are two options for the installation of the hardware: either the construction of new charging stations or the retrofitting of existing charging stations. When the BEV approaches the charging station, the RSU establishes the connection between the BEV and the charging station when it detects the OBU. The vehicle is recognized, and the required data is transferred to the unit. After establishing communication between the BEV and the charging station, the intention to charge must also first be confirmed. The vehicle driver is then prompted to enter a code or password on the internal display to authorize payment and start the charging process. Thus, only confirmation and code entry are required. However, this requires a payment method to be set in advance as the default payment method, which is automatically selected for each charging process. Also an authorization for money collection, similar to a SEPA direct debit mandate, is required. The charging process is started by plugging the charging cable into the charging socket of the vehicle. In the following Figure 2 the schematic process of the solution approach is presented.

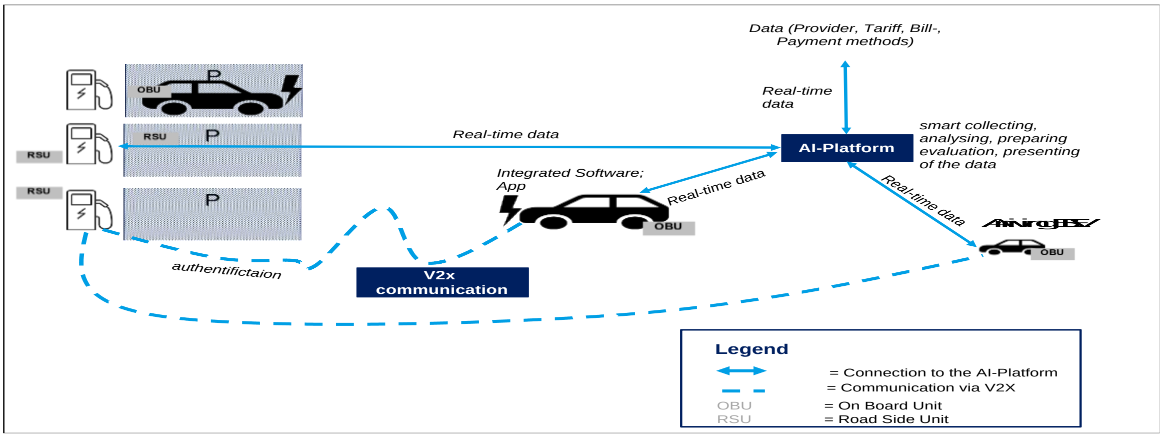

Figure 2: Schematic process of the solution approach

4. Results

Based on the solution approach, all process steps, such as authentication and authorization, connecting the charging cable, starting the charging process, ending the charging process (ct. 3.1.1.) are eliminated, except for the step that the charging cable must be plugged into the car and removed again at the end of the charging process. The solution approach enables a comprehensive, optimized, and partially automated charging process. Partially automated, that the driver still has to plug in and unplug the cable on his own. Due to the combination of AI and V2X, the driver gets an overview of all charging stations e. g. Germany, of all possible prices and uniform access to the charging station based on V2X. The driver can overview everything in the car through the special software or interface. This increases the convenience for the BEV driver enormously and thus makes the process consumer-friendly. Besides there is the benefit that the driver receives analyses and recommendations for action from the AI. However, many aspects need to be answered in the research process:

- the legal characterization and concretization of the contractual relationships (e. g. ePerson)
- data protection
- specifications of the AI
- specific modifications that must be made and the costs
- technical design and design of the software

5. Summary

As some studies have already shown, there are still massive problems today with the charging infrastructure, or more precisely the charging process from the customer's point of view. The charging process is one of the most important elements of electromobility and is an important factor for the green transportation transition. Unless the CPOs change despite the criticism from politicians and BEV drivers, research has to do its part and make the process consumer-friendly. Currently, there are already some approaches from research as well as from industry that address the issue, but not yet comprehensively. The approach presented here is intended to change this and optimize the charging process from the formation of the contract to the end and beyond, making it as easy as possible for BEV drivers. The approach can be further developed and supplemented. The following aspects can be considered:

- complement of a parking space monitoring (e. g. autonomous bollard),
- integration of other approaches (e. g. PnC, blockchain technology (DLT)),
- the outlook in the direction to autonomous driving,
- inductive charging (e. g. at the traffic lights),
- supply of the electricity to the power grid (ct. charging station from NewMotion like mentioned before).

References

[1] A. Dias and A. Bade, "Akzeptanz der Systemintegration von Elektrofahrzeugen", 2020. [Online]. Available: https://www.energie.de/et/news-detailansicht/nsctrl/detail/News/akzeptanz-der-systemintegration-von-elektrofahrzeugen-20201462/. [Accessed 20th 01 2021].

[2] A. Auf der Maur, N. Brüggeshemke and M. Kutschera, Lade-Report, Basel: Prognos AG, 2020.

[3] LichtBlick, LichtBlick-Ladesäulencheck 2020, Hamburg, 2020.

[4] EUPD, Vergleichsanalyse mobiler Ladestromtarife 2020, Bonn: EuPD Research Sustainable Management GmbH, 2020.

[5] BfDI, "Elektromobilität", [Online]. Available: https://www.bfdi.bund.de/DE/Datenschutz/Themen/Reisen_Verkehr/ElektromobiliaetArtikel/Elektromobilitaet.html. [Accessed 20 01 2021].

[6] BDEW, Meinungsbild E-Mobilität, Berlin, 2019.

[7] "Mehr Wettbewerber und steigende Kosten bei mobilen Ladetarifen für Elektromobilität Empty", 14 06 2020. [Online]. Available: https://www.emobilserver.de/nachrichten/energie-ladetechnik/2268-mehr-wettbewerber-und-steigende-kosten-bei-mobilen-ladetarifen-für-elektromobilität.html. [Accessed 15 03 2021].

[8] ADAC, "Ladestationen für Elektroautos: Das kostet der Strom", 2020. [Online]. Available: https://www.adac.de/rund-umsfahrzeug/elektromobilitaet/laden/elektroauto-ladesaeulen-strompreise/. [Accessed 20 01 2021].

[9] Schaufenster Elektromobilität(BuW), "Good eRoaming Practice: Practical Guide to Interconnecting the Charging Infrastructure in the Electromobility Showcases".

[10] Bitkom, "Stellungnahme: Plug & Charge mittels ISO 15118 – Herausforderungen bei der Umsetzung", 07 05 2020. [Online]. Available: https://www.bitkom.org/sites/default/files/2020-05/200507plugncharge.pdf. [Accessed 30 03 2021].

[11] C. Hahn und A. Grün, „Aufbau eines eRoaming-Systems für Elektromobilität“, [Online]. Available: https://www.kim.tu-berlin.de/fileadmin/fg280/veranstaltungen/kim/konferenz_2013/vortraege/wie_kann_ein_sinnvolles_rollenmodell_fuer_eine_roaming_loes

ung_in_der_elektromobilitaet_aussehen.pdf. [Zugriff am 30 03 2021].
[12] C. Kloth, "BLOCKCHAIN-STARTUP WILL E-AUTOS AN DER LADESÄULE ZAHLEN LASSEN", 18 02 2021. [Online]. Available: https://www.energate-messenger.de/news/209838/blockchain-startup-will-e-autos-an-der-ladesaeule-zahlen-lassen. [Accessed 30 03 2021].
[13] D. Marinkanovic , "Österreich: Blockchain-Ladestation für Elektroautos wird erstmalig in Wien aufgestellt", 31 03 2019. [Online]. Available: https://kryptoszene.de/news/oesterreich-blockchain-ladestation-fuer-elektroautos-wird-erstmalig-in-wien-aufgestellt/. [Accessed 30 03 2021].
[14] Bosch, "Cars that negotiate with charging stations", [Online]. Available: https://www.bosch.com/stories/dlt-cars-that-negotiate-with-charging-stations/. [Accessed 30 03 2021].
[15] G. C. Congress, "ABB, Fastned support Autocharge automatic authorization for charging sessions", 18 10 2017. [Online]. Available: https://www.greencarcongress.com/2017/10/20171018-abb.html. [Accessed 27 04 2021].
[16] FEIG, "MILESTONE FOR E-MOBILITY: UNIVERSAL PAYMENT SYSTEM CVEND BOX+ EMBEDDED IN CHARGING STATIONS FROM WIRELANE", 24 03 2021. [Online]. Available: https://www.feig.de/en/news/press-news/detail/view/milestone-for-e-mobility-universal-payment-system-cvend-box-embedded-in-charging-stations-from-wir/. [Accessed 06 04 2021].
[17] NewMotion, "V2G makes way for V2X ", 17 10 2018. [Online]. Available: https://newmotion.com/en-gb/knowledge-centre/news-and-updates/v-2-g-makes-way-for-v-2-x. [Accessed 30 04 2021].
[18] J. L. Gschwend und G.-R. Wiher, „Automatic EV Charging-Point Authentication Using V2X Communication“, 2019. [Online]. Available: https://www.ost.ch/fileadmin//dateiliste/97_daten/abstracts/93d1eb4f-e646-4840-8c99-a1c1b91450ce.pdf. [Zugriff am 06 04 2021].
[19] H. ElHusseini, C. Assi, B. Moussa, R. Attallah and A. Ghrayeb, "Blockchain, AI and Smart Grids: The Three Musketeers to a Decentralized EV Charging Infrastructure", IEEE Internet of Things Magazine, no. 3, pp. 24-29, 2020.
[20] J. Donghan and J. Kui, "Charging Infrastructure Intellectualization and Future of Different Automotive Powertrains", Joule,, vol. 8, no. 4, pp. 1634-1636, 2020.
[21] Y. Shen, W. Fang, F. Ye and M. Kadoch, "EV Charging Behavior Analysis Using Hybrid Intelligence for 5G Smart Grid", Electronics, vol. 1, no. 9, p. 80, 2020.
[22] E. S. Xydas, C. E. Marmaras, L. M. Cipcigan, A. S. Hassan and N. Jenkins ,"Forecasting Electric Vehicle charging demand using Support Vector Machines," 48th International Universities' Power Engineering Conference (UPEC), pp. 1-6, 2013.
[23] D. M., A. Moeini and A. Kavousi-Fard, "Reinforcement Learning-Based Load Forecasting of Electric Vehicle Charging Station Using Q-Learning Technique", IEEE Transactions on Industrial Informatics, vol. 6, no. 17, pp. 4229-4237, 2021.
[24] J. Zhu, Z. Yang and M. Mourshed", Electric Vehicle Charging Load Forecasting: A Comparative Study of Deep Learning Approaches," Energies , vol. 14, no. 12, p. 2692, 2019.
[25] S. D. Ramchurn, P. Vytelingum and e. al., "Putting the 'smarts' into the smart grid: a grand challenge for artificial intelligence", Communications of the ACM, vol. 4, no. 55, 2012.
[26] Opdi-tex, "Kamerabasierte Belegungserkennung per künstlicher Intelligenz", [Online]. Available: https://www.opdi-tex.de/produkte/opdipark-belegungserkennung-per-ki/. [Accessed 06 04 2021].
[27] J. Kral, "City-Planung: Ford ermittelt per KI beste Standorte für Ladesäulen", 09 04 2019. [Online]. Available: https://vision-mobility.de/news/city-planung-ford-ermittelt-per-ki-beste-standorte-fuer-ladesaeulen-3904.html. [Accessed 06 04 2021].
[28] E-Autos.de, "Aufladen eines Elektroautos", [Online]. Available: https://www.e-autos.de/technik/aufladen-eines-elektroautos/. [Accessed 01 04 2021].
[29] A. Sommer, "Bezahlen an Elektroauto Ladestationen: So gehts", 24 05 2019. [Online]. Available: https://efahrer.chip.de/e-wissen/bezahlen-an-elektroauto-ladestationen-so-gehts_10759. [Accessed 01 04 2021].
[30] Eon, "Wie wird ein E-Auto geladen?", 02 2019. [Online]. Available: https://www.eon.de/de/eonerleben/laden-von-elektroautos.html. [Accessed 30 03 2021].
[31] Goingelectric", Laden an öffentlichen Ladepunkten," [Online]. Available: https://www.goingelectric.de/wiki/Laden-an-oeffentlichen-Ladepunkten/. [Accessed 30 03 2021].
[32] J. Ranlau, Handlungsleitfaden: Aufbau von elektromobiler Ladeinfrastruktur, Glücksburg/ Ostsee: Artefact gGmbH, 2017.

Intelligent collaborative and Cooperative Transport Agents in Logistics Applications

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Abstract

In the advancements of industrial transport systems, there is a demand for intelligent autonomous transport agents in the manufacturing industries. Unlike conventional transport systems such as forklifts, vacuum lifters, cranes, the Multiple transport agents can efficiently transport large cargo through various locations in the industry. Moreover, these transport agents can perform the cooperative task of shifting large assembling parts from one location to another inside a large factory. In such situations, the transport agents should communicate and collaborate with neighbouring transport agents to accomplish such a highly complex task.

However, several research issues and challenges develop, manage, and coordinate the before-mentioned transport agents. The main issues addressed in this work are managing the fleet of transport agents to perform a single operation, identifying the limitations in obtaining swarm behaviour of transport agents and cooperative movement of agents at various paths between start and endpoint of the transportation area (in terms of corners).

This paper proposes the research idea and methodologies for addressing the issues and possible solution approaches concept for building such intelligent transport agents. Furthermore, this paper presents the conceptual framework for IKoTrans in an intralogistics environment. The forefront of swarm intelligence and artificial intelligence allows us to integrate specific technologies to assemble sophisticated transport agents for logistic applications.

1. Introduction

In production and Intrastate logistics, moving cargo containing parts of a product is frequent within the factory premises. Conventional transport systems such as forklifts, cranes, and vacuum grippers carry out transportation operations with human intervention. However, there are few problems with the approaches mentioned above regarding safety, stability, efficiency. As the human workers control the operation of all the approaches, safety plays a significant role in choosing a type of transportation mode.

Nowadays, the research focuses on autonomous transport agents in the manufacturing industry. We have conventional line followers used to transfer goods between manufacturing cells. Nevertheless, there are few bottlenecks with the line followers with obstacle avoidance, predefined path planning, and static environment. These line followers and few autonomous transport agents can transport the goods based on their dimensions. What if the dimension of the transportation good is large? A single transport agent cannot carry it alone.

Therefore, we propose Intelligent collaborative and cooperative Transport agents (IKoTrans) as a mode of transportation to transfer large cargo in between various factory locations. Furthermore, this paper presents the concept to use multiple intelligent transport agents to perform necessary transport operation.

The IKoTrans are programmed as follows:

- Can learn the dynamic environment and acts according to the situation.
- Avoids actions that cause damage to property or humans.
- Can perform obstacle avoidance
- Can perform tasks/actions with less or without human interaction for a particular period.
- Can adopt any changes in the environment.
- Can navigate autonomously from point to point.
- A fleet of IKoTrans can collaboratively perform a single complex task.
- Each transport agent can perform autonomous navigation in an unknown environment.

- It also performs path planning, inter-agent communication, Fleet formation.

1.1. Research questions

The main research Idea of the IKoTrans is to provide a sustainable transportation system for intralogistics. Therefore, the following research questions need to be addressed to build a system that can integrate the IKoTrans:

- What is the behaviour of transport agents in an unknown dynamic environment?
- How the transport agents communicate with the environment and other transport agents?
- How the transport agents move simultaneously in a flock carrying cargo?
- What are the path planning strategies for single stop and multi-stop destinations?

2. System Description

2.1. System Design

Figure 1 describes the various elements in the workflow of the integration of IKoTrans transport mode in Intralogistics. The transport agents can drive autonomously from the production area to the assembling or dispatch area. The operational control center (OCC) is responsible for task generation and fleet distribution. In the factory layout, the area which requires transportation can request the operational control center for IKoTrans with the transportation parameters such as type of goods that need to be transported. Based on the received information, the OCC can assign the fleet of transport agents. Once the task finished, the transport agents update its state to the OCC. The main operation of OCC is to assign the fleet to a particular source and destination. The inbuilt intelligence of IKoTrans can calculate path planning, routing and obstacle avoidance in the dynamic environment. Unlike line followers, the IKoTrans do not wait for the obstacle to be cleared instead they find a new path around the obstacle which makes them more efficient and reliable.

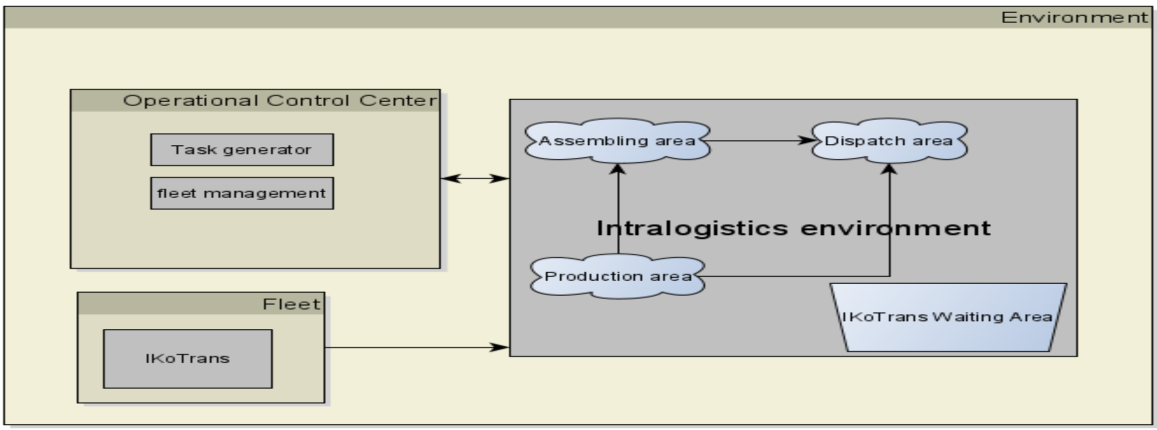

Figure 1: Operation workflow of IKoTrans transport mode in Intralogistics

3. Literature study

In this section, the literature provides the fundamental knowledge about the multi-transport agents, communication, path planning algorithms and flocking algorithms.

Panait and Luke [1] discussed the various topics on multi-agents and their state of the art. They discussed multi-agent learning through machine learning techniques, stating that reinforcement learning is useful where reinforcement information is provided. RL has two learning techniques:

- Q-Learning: it learns the usage of states where agents perform actions
- Temporal difference: it learns about the agent states.

Team Learning is a concept in which a learning agent experience the environment and forms a set of actions, followed by other team agents. Types of team learning are homogeneous and heterogeneous team learning. In homogeneous learning, all agents have to perform the same set of actions that differ from agent to agent. Concurrent learning is a technique where agents have their unique learning techniques and agents form their learning experiences. Communication between agents is classified as Direct and indirect

Kong et al. discussed the master-slave approach in deep multi-agent reinforcement learning. In this approach, several multi-agent tasks performing problems with policy gradient networks are solved. First, agents (slaves) sends messages to the master. Next, the master sends a unique set of messages to each slave. In turn, slaves decide their actions to reach the goal [2].

Engel et al. proposed a SLAM algorithm that runs in real-time, tracking a global map of surroundings. This can switch between differently scaled environments. It is named LSD-SLAM as it is a large-scale direct monocular SLAM [3].

Many techniques are introduced to solve the challenges in path planning. For example, Yang et al. proposed a navigation system using NYUv2 data-set with CNN technique. a Convolutional Neural network is used to predict efficient path by creating the depth of normal images by which obstacle positions are detected [4].
Koenig et al. proposed the D* Lite algorithm, which continuously maps the shortest path towards the goal. D* Lite is the same as A* algorithm, which can find the shortest path from the initial point to the goal point, but D* Lite is modified to continuously find the shortest path from the current position to destination [5]. Maurovic et al. proposed path planning for an active SLAM. Modifications in the D* algorithm with negative weights is used for finding the shortest path [6].

4. Methodology

In order to evaluate various behavioural insights of the IKoTrans, we choose simulation study as our methodology. Figure 2 shows the conceptual framework for the IKoTrans simulation environment. The conceptual model presents the abstract modelling of the IKoTrans and visualising their interaction with the environments.

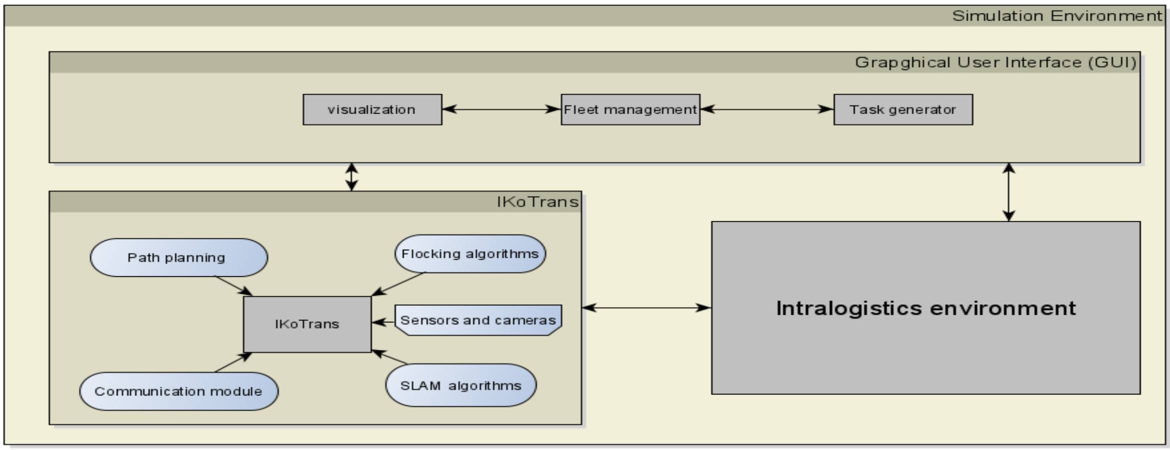

Figure 2: Conceptual framework for IKoTrans Simulation Environment

4.1. Graphical User Interface (GUI)

It contains a task generator, fleet management and visualisation submodules, and an intralogistics environment and an IKoTrans fleet interface. GUI acts as a moderator between the environment and IKoTrans. It processes the transportation order from the environment by assigning the transport agents for the particular transport operation using the task generator submodule.

4.2. Agents and Environment

The transport agents consist of controller cameras, obstacle detectors, laser sensors, and autonomous navigation and driving algorithms. We use a Robotic operating system (ROS) to implement and realise the system in the simulation environment. ROS is an open-source software environment that provides the necessary interfaces to integrate and evaluate different algorithms of IKoTrans. ROS provides gazebo and RVIZ to implement and visualise the actions of IKoTrans in the simulation environment. A dynamic intralogistics environment can realise using the gazebo software package in ROS.

4.3. Communication between Agents

Communication between the agents can be established by reinforcement learning, swarm algorithms and by many other techniques. There are several types like centralised learning, decentralised learning, concurrent learning, state learning. Jacob et al. Proposed a reinforcement learning approach that uses centralised learning and decentralised execution [3]. Following this process, they proposed two approaches, Reinforced inter-agent learning (RIAL) and Differentiable inter-agent learning (DIAL). RIAL approach uses Deep Q-learning, which has a learning phase and execution phase, in which the learning phase has two variants.

- Agents independently learn their network technique by considering all other agents present as part of the environment.
- Trains a single network for all the agents in the environment. This network shares the variables among all.

In the execution phase, the agents decide the action according to the observations received. DIAL approach, a communication channel, is developed which is used to transfer real-valued messages between agents in centralised learning. It is a deep learning approach as this shares gradients from agent to agent. In the execution phase, shared messages are categorised, and agents decide their actions according to categorised real-valued messages [7]. Information on the environment is shared between the agents during communication, which agents gain with the SLAM approach. RIAL and DIAL are techniques used for establishing communication between agents. The transport agents start moving in the virtual environment individually and share their experiences with other agents through a communication channel.

4.4. Integration of SLAM

SLAM is abbreviated as Simultaneous Localisation and Mapping, in which the agent moves in the environment by storing its position and mapping its path simultaneously. Thus, the transport agent autonomously navigates even in an unknown environment using the three components:

- Sensing devices (cameras/Laser sensors) equipped to the transport agent used to grab the information from the environment.
- Algorithms are used to save information collected by sensors and allows the robots to move further.
- Implementation: Algorithms allow the transport agent to move (take actions) and explore if any areas are unexplored.

The transport agents are made to move in the created virtual environment. They learn and localise the environment through SLAM. This movement of agents in the environment is visualised in gazebo and rviz, visual simulators in ROS. Obstacles are added later to observe the changes in the movement of agents. One of the recent approaches for the SLAM algorithm is investigated by Wen et al. They proposed an active SLAM approach, in which SLAM is integrated with path planning using a deep reinforcement learning algorithm(DRL). DRL algorithm is used for agent and environment interaction and uses a deep q network to learn about the environment and further actions. Robot integrated with DRL navigates in the environment and builds the map. If any Obstacle in the path is detected, it defers the path before reaching the minimum distance between the robot and obstacle to avoid collision [8]. This approach succeeded in finding a path between two points, but it may not be the shortest path. To obtain the shortest path, we have many algorithms like Dijkstra, A*, D* etc.

4.5. Path Planning

4.5.1. Single-stop

Dijkstra algorithm is the shortest pathfinding algorithm. It is the oldest and first shortest path algorithm implemented in 1956 [9]. It assumes the initial distance as 0 at the initial point and checks all possible nearest vertices, and investigates the shortest distance to reach the adjacent point. This process continues until it reaches a point where there are no adjacent points. This process obtains the shortest path between points. A* algorithm is the first best search algorithm similar to the Dijkstra algorithm in which it finds all possible paths, and the least distance path is considered the shortest path. This algorithm acquires the shortest path much active than Dijkstra's [10]. The cost function is

$$F = G+H \quad (1)$$

F is the cost of the node, G is cost to reach the node, and H is the heuristic function. D* Lite algorithm is similar to A*, but this determines the shortest distance from the current point to the goal point. This algorithm does not calculate any edge costs of moving towards or far away from the current vertex.

4.5.2. Multi-stop

The Floyd-Warshall algorithm [11] is a shortest path algorithm like Dijkstra's algorithm. However, Dijkstra is a single-source, shortest-path algorithm. This means it only computes the shortest path from a single source. Floyd- Warshall, on the other hand, computes the shortest distances between every pair of nodes.

Floyd-Warshall will tell the optimal distance between each pair of nodes. For example, it will tell the agent that the quickest path from one node to another node is based on the connecting edge weights. Nevertheless, it will also tell the agent the quickest path between all the nodes in the network. This is very useful for transport agents with multiple stops. With the help of this algorithm, the shortest and the fastest path can be plotted.

4.6. Fleet Movement

4.6.1. Flocking Algorithm

Flocking is the collective motion by a group of self-propelled entities exhibited by many living beings such as birds and small marine life such as fish. Craig Reynolds has first proposed the Flocking algorithm, and it has been extended several times since then. There are three simple and basic rules for a flocking algorithm to work efficiently[12].

- Separation: avoid crowding neighbours
- Alignment: steer towards the average heading of neighbours
- Cohesion: steer towards average position of neighbours

Additionally, a new set of rules can be given to the IKoTrans depending on the environment in which it will operate. By applying a flocking algorithm to transport agents, there are several advantages.

- In a flock(group of transport agents), all agents steer towards the common goal.
- Each agent in the flock keeps an optimal distance to their neighbours in all directions.
- When a flocking algorithm is used, there is no unique leader in the flock. Instead, each agent acts as its leader. This recovers the major flaw stated with the leader-follower method.
- If an agent breaks down in a flock, the other agents consider the immobilised agent as an obstacle and find a new path around it. This can

be modified by giving additional rules in case multiple transport agents are immobilised.
- The agents in the flock can be grouped and act as a unit for transporting heavy cargo.

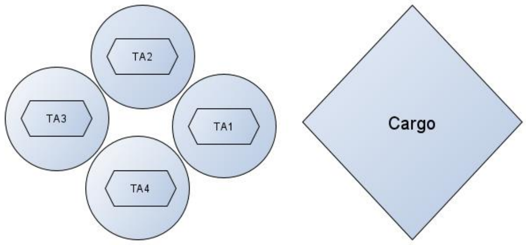

Figure 3: Flocking and optimal distance of IkoTrans carrying a cargo

4.6.2. Failure of single or more transport agents in a Flock

Every transport agent keeps an optimal distance to its neighbours and any obstacles in the environment. Figure 3 shows the optimal distance between the transport agents in a circular shape. The optimal distance is measured from the center of the transport agent. In the event of 2 transport agents getting close, the three rules of the flocking algorithm come into play and then the agents disperse according to separation and soon follows the alignment rule. In light cargo transportation where one transport agent (TA1) can carry a cargo item by itself, and if TA1 is a member of a flock and immobility of this TA1 does not hinder the operation of the rest of the flock. As each transport agent in a flock acts as its leader, in case of heavy cargo transportation where multiple transport agents from a flock under a cargo platform move it. Checks if the rest of the functional transport agents can carry out the task at the cost of speed relative to time. If one of the transport agents in the flock gets immobilised, it can have two solutions.

- Suppose the time taken to reach the destination is more than replacing the Transport agent. In that case, a new transport agent is introduced into the flock, and it keeps an optimal distance from the rest of the agents.
- The agents underneath the platform consider the immobilised transport agent as an obstacle and automatically re-position themselves without breaking the rules of the flocking algorithm.

5. Summary

The main of this paper was to present the idea and importance of integration of IKoTrans in intralogistics. Furthermore, the paper demonstrated the conceptual model with various accepts of autonomous multi-transport agents such as communication between transport agents, autonomous navigation with SLAM algorithms in unknown environments, path planning, simultaneous fleet movement using flocking algorithms. This research illustrated the different stages of building IKoTrans to perform sustainable transportation for carrying large cargos inside the factory environment.

Future work of this research will be building a simulation environment to investigate and evaluate the path planning algorithms, flocking algorithms and testing the dynamic environment with flocking behaviour of the IKoTrans. We aim to build a dynamic simulation environment to verify and optimise the various algorithms of IKoTrans in intralogistics.

References

[1] L. Panait and S. Luke, 'Cooperative multi-agent learning: The state of the art', *Auton. Agent. Multi. Agent. Syst.*, vol. 11, no. 3, pp. 387–434, 2005, doi: 10.1007/s10458-005-2631-2.

[2] X. Kong, B. Xin, F. Liu, and Y. Wang, 'Revisiting the Master-Slave Architecture in Multi-Agent Deep Reinforcement Learning', no. 2016, pp. 1–14, 2017.

[3] J. Engel, T. Schöps, and D. Cremers, 'LSD-SLAM: Large-Scale Direct monocular SLAM', *Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics)*, vol. 8690 LNCS, no. PART 2, pp. 834–849, 2014, doi: 10.1007/978-3-319-10605-2_54.

[4] S. Yang, S. Konam, C. Ma, S. Rosenthal, M. Veloso, and S. Scherer, 'Obstacle Avoidance through Deep Networks based Intermediate Perception', 2017.

[5] S. Koenig and M. Likhachev, 'Improved fast replanning for robot navigation in unknown terrain', *Proc. - IEEE Int. Conf. Robot. Autom.*, vol. 1, no. May, pp. 968–975, 2002, doi: 10.1109/robot.2002.1013481.

[6] I. Maurovic, M. Seder, K. Lenac, and I. Petrovic, 'Path Planning for Active SLAM Based on the D∗ Algorithm with Negative Edge Weights', *IEEE Trans. Syst. Man, Cybern. Syst.*, vol. 48, no. 8, pp. 1321–1331, 2018, doi: 10.1109/TSMC.2017.2668603.

[7] J. N. Foerster, Y. M. Assael, N. De Freitas, and S. Whiteson, 'Learning to communicate with deep multi-agent reinforcement learning', *Adv. Neural Inf. Process. Syst.*, no. Nips, pp. 2145–2153, 2016.

[8] S. Wen, Y. Zhao, X. Yuan, Z. Wang, D. Zhang, and L. Manfredi, 'Path planning for

active SLAM based on deep reinforcement learning under unknown environments', *Intell. Serv. Robot.*, vol. 13, no. 2, pp. 263–272, 2020, doi: 10.1007/s11370-019-00310-w.
[9] T. D. Le, 'Search-Based Planning and Reinforcement Learning for Autonomous Systems and Robotics'.
[10] G. Abhishek, M. Prateek, L. Rishabh, and S. Neeti, 'Path Finding: a* or Dijkstra'S?', *Int. J. IT Eng.*, vol. 02, no. 01, pp. 1–15, 2014.
[11] P. Tucnik, T. Nachazel, P. Cech, and V. Bures, 'Comparative analysis of selected path-planning approaches in large-scale multi-agent-based environments', *Expert Syst. Appl.*, vol. 113, pp. 415–427, 2018, doi: 10.1016/j.eswa.2018.07.001.
[12] C. W. Reynolds, 'Flocks, herds, and schools: A distributed behavioral model', *Proc. 14th Annu. Conf. Comput. Graph. Interact. Tech. SIGGRAPH 1987*, vol. 21, no. 4, pp. 25–34, 1987, doi: 10.1145/37401.37406.

Handling of Logistic Deadlocks with Machine Learning

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1. Abstract

Deadlocks are not sufficiently considered in the planning of logistic systems. Due to the increasing automation in logistics systems, possible deadlock situations will occur more and more frequently in the future. The previous methods for preventing, avoiding and resolving deadlocks are not suitable for larger, cross-resource systems, and the most recent approaches using machine learning are not yet mature enough.

Therefore, this dissertation aims to make a fundamental contribution to understanding the interaction of deadlocks with machine learning methods and to research the technical feasibility in different application scenarios. On the one hand, it will be examined whether the use of self-learning AI agents must lead to a paradigm shift in the strategic approaches to dealing with deadlocks and, on the other hand, where the current limits of machine learning methods for dealing with deadlocks lie.

2. Introduction

As a key topic of discussion in production and logistics, Industry 4.0 confronts companies with very pragmatic challenges in terms of digitization and automation. For German companies, the relevance of specific technologies such as automated guided vehicles (AGVs) and robotics has therefore increased significantly in recent years [1]. Due to the increasing use of automated systems in companies, the planning and control of the respective systems is becoming more and more complex, since the interaction of individual systems is highly individual for the respective company and the answers of the industrial solutions are not holistic. In the worst case, there is a risk of deadlocks, which can bring the entire (logistic) system to a standstill through chain reactions. Deadlocks arise when at least two processes (operations) wait for each other in the form of a circular reference and cannot carry out the next process step due to conditions that cannot be met [2, 3]. According to Tanenbaum, a widespread type of deadlock is considered here: a resource deadlock, but referred to below only as a deadlock. Deadlocks can also occur if not all resources in a system are used [2].

Figure 1 and Figure 2 show that deadlocks can arise even under the simplest conditions. Figure 1 shows a conceptual model of a production-logistical deadlock that arises because the finished product 2 wants to claim the robot arm C. Robot arm C is occupied by square 4 and is to place square 4 on production station A next. However, there is already square 3 waiting for transport by robot arm D. A circular resource request is created, which is represented by the arrows and cannot be resolved without additional capacities, such as an additional buffer space.

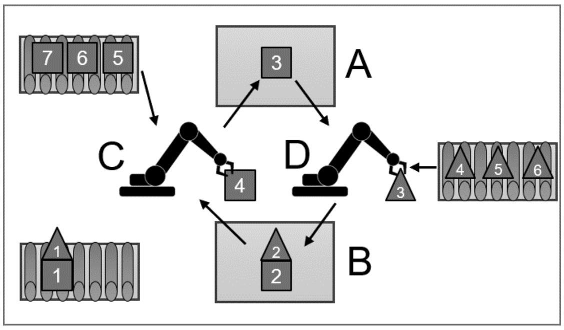

Figure 1: Conceptual model of a production-logistical deadlock

Figure 2 shows a typical intralogistic situation with driverless transport vehicles (AGVs) on single-lane routes. AGV 1 has route section 4 as the destination. If AGV 2 drives on route segment 3 beforehand, a deadlock arises that can only be resolved by reversing or an evasive maneuver on route section 2.

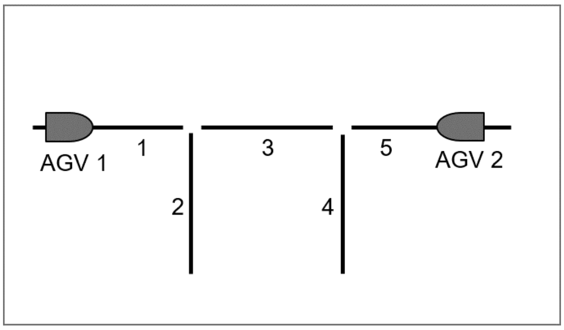

Figure 2: Conceptual model of an intralogistic scenario, which can lead to a deadlock

3. Literature

There are different, problem-specific approaches to handle deadlocks. Most of these approaches do not come from logistics at all, but from computer science, where this problem was recognized and discussed since the late 1960s and early 1970s [2, 4, 5]. Deadlocks mainly occurred in parallel/ multi-programming and general strategic approaches were developed to break the conditions for the occurrence of deadlocks. The four conditions defined by Coffman et al. have always been considered as starting points for dealing with deadlocks and are also used for current problems [2, 6–8]:

1. “Tasks claim exclusive control of the resources they require ("mutual exclusion" condition).
2. Tasks hold resources already allocated to them while waiting for additional resources ("wait for" condition).
3. Resources cannot be forcibly removed from the tasks holding them until the resources are used to completion ("no preemption" condition).
4. A circular chain of tasks exists, such that each task holds one or more resources that are being requested by the next task in the chain ("circular wait" condition).” [2]

In addition to the focus on breaking one of these conditions for a deadlock, a distinction was made between three basic, strategic approaches to handle deadlocks [2]:

- prevention
- avoidance
- detection & resolution

In the logistics planning of processes and systems, deadlocks only play a role late, if at all, in the operational detailed planning of control strategies. It is then usually too late for a deadlock prevention approach. The typical approaches for planning logistic systems like

- the process chain-based planning according to Kuhn and Bernemann [9],
- the VDI guideline for system identification of order picking systems [10],
- the phases of planning and implementation of logistics systems according to Gudehus [11],
- and the four-stage procedure for planning transport systems according to van Bonn [12]

do not consider deadlocks for dimensioning the resources or planning the infrastructure. For example, Gudehus [11] explains in detail how the goals of “transport optimization” and “space minimization” can be achieved in the design of logistics halls by means of gate arrangements and other measures. However, neither in the design of the logistics hall nor in the planning and dimensioning of the transport system, Gudehus addresses possible deadlock situations that could occur with a supposedly favorable design. In the case of the other sources mentioned, the problem of deadlocks is also not mentioned in any way and one can only speculate what effects an identified deadlock situation would have on the corresponding procedure.
As a result, deadlocks are often not recognized in advance of planning, but only when the control and decision-making rules are tested. This happens, for example, in a simulation model which, after numerous simulation runs, produces even improbable constellations in the system that lead to a deadlock. The handling of deadlock problems in logistics then often takes place with additional problem-specific control rules [13] or with preventive, deterministic measures through advance planning and reservation of resources [14, 15], assumed that the information available is sufficient for this deterministic solution. Both approaches require a central control solution and do not scale well with larger systems.
Decentralized control approaches in logistics that promise such scalability have also relied on problem-specific avoidance rules through optimization algorithms for deadlocks [16, 17] and on agent-based approaches [18–21]. Since the most recent advances in the field of machine learning processes [22], control tasks have increasingly been performed by machine-trained artificial neural networks (ANN). In the literature, an approach of reinforcement learning is often used and the occurrence of deadlocks is only briefly discussed [23–26]. A more intensive

investigation into how deadlocks affect machine learning processes and whether the AI agents actually learn to deal with the deadlocks has not yet been fully clarified. The most detailed statements on this could only be found in a current article by Sørensen et al. [27] can be found. The authors implemented a reinforcement learning approach with multilayer networks for a baggage system at the airport, which was expanded with a deadlock avoidance algorithm. The AI agent was able to reduce the number of deadlocks, but could not entirely avoid them. Deadlocks occurred more frequently, especially with the increase in luggage volume, and led to the restart of the episode in the learning environment.

In summary, it can be said that deadlocks are not adequately considered in the planning of logistic systems. Due to the increasing automation in logistics systems, possible deadlock situations will occur more and more frequently in the future. The previous methods for preventing, avoiding and resolving deadlocks are not suitable for larger cross-resource systems and the most recent approaches using machine learning are not yet mature enough.

Therefore, the dissertation should make a fundamental contribution to the understanding of the interaction of deadlocks with machine learning methods and research the technical feasibility in different application scenarios. On the one hand, it is to be examined whether the use of self-learning AI agents has to lead to a paradigm shift in the strategic approaches for dealing with deadlocks and, on the other hand, where the current limits of machine learning methods for dealing with deadlocks lie.

4. Solution approach

The dissertation is divided into three consecutive points.

Firstly, corresponding application possibilities of machine learning processes in deadlock-capable logistics systems must be identified and limited. This means that various operational decision problems must be analyzed, which can be taken over by AI agents. Appropriate machine learning approaches and network structures need to be selected, which appear to be the most promising based on the current literature.

Second, several technical prototypes are to be developed for the selected fields of application. In a simulation model, the developed AI agents are trained and evaluated in numerous random experiments. Here, attention should also be paid to special features in the learning phase of the different agents.

Thirdly, by inducing the findings from the exemplary prototypes and the simulation results, general statements should be made about the interrelationships between deadlocks and various machine learning processes. It should also be assessed to what extent the previous strategy approaches with prevention, avoidance or resolution are still applicable in machine learning processes and which new strategies for dealing with deadlocks can be considered in the context of machine learning.

The use of artificial, neural networks (ANN) is planned for the development of the technical prototypes. These networks should be learned with the help of simulation models and enabled in deadlock-capable systems to improve the handling of deadlocks through decisions. Measurement criteria are classic logistical key figures such as throughput, utilization, stock levels and average queue length as well as deadlock-specific key figures such as number of deadlocks, additional waiting times and additional detours.

The aim is to investigate at which point the use of artificial, neural networks would make sense and whether the machine learning approaches are superior to the previous methods for avoiding and resolving deadlocks. Figure 3 shows examples of possible uses of artificial, neural networks for dealing with deadlocks in a driverless transport system. Conceptually, the classification of the possible uses is still based on the previous strategic approaches for dealing with deadlocks. When using artificial, neural networks to detect deadlocks (see Figure 3, top), an approach of supervised learning is likely to be more productive than an approach of reinforcement learning. In order to limit the scope of work and ensure the necessary depth of the investigations in the project, focus is therefore on approaches of reinforcement learning. The detection of deadlocks can be carried out quickly in terms of graph theory and analysis. A development of a machine learning approach for deadlock detection is therefore regarded as interesting, but a sufficiently large benefit compared to the development effort is not foreseeable. As a result, the dissertation is limited to avoiding and resolving deadlocks, although it cannot be completely ruled out that the AI agents will learn a certain type of recognition on their own.

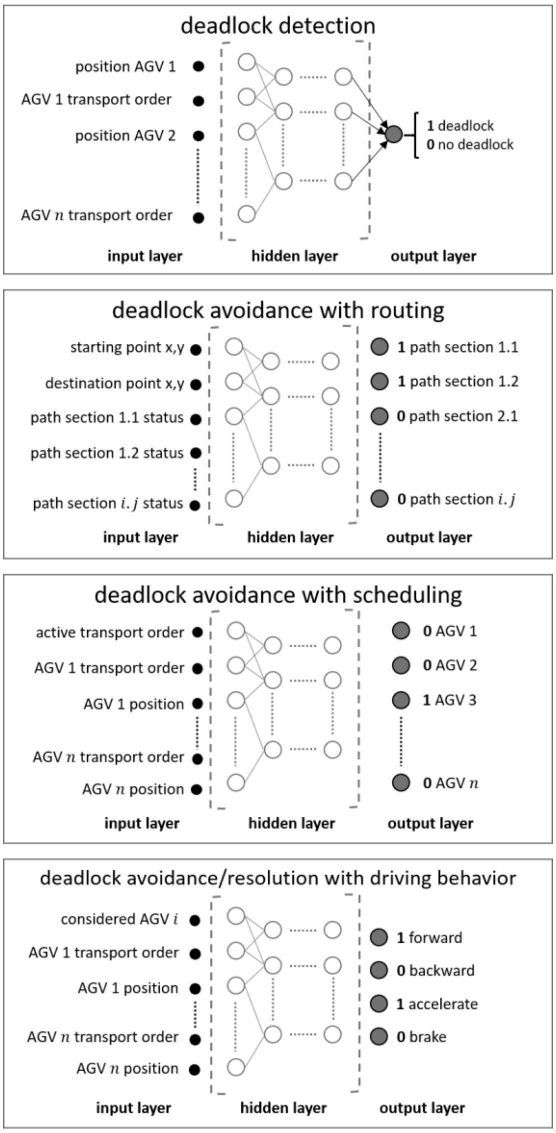

Figure 3: Exemplary possible uses of artificial, neural networks for dealing with deadlocks in a driverless transport system

Another aspect of the dissertation is the investigation of which positioning of the AI agents favors learning behavior. Figure 4 shows three approaches for locating the AI agent in the form of artificial, neural networks. A multi-agent system in which every AGV would receive a copy of the network that was learned would be a very decentralized approach. Here the agents would have to learn cooperative behavior. With an AI that takes control over a sector, the intelligence is located in the infrastructure. The agents of the sectors would presumably have to consist of differently trained networks. Cooperation between vehicles in one sector would be guaranteed, but competitive behavior between the sectors and complications at sector boundaries could arise.

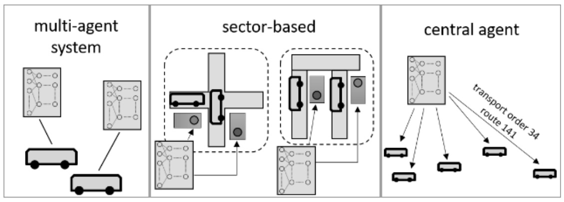

Figure 4: Conceptual model for locating the artificial intelligence for a driverless transport system

A central agent could optimize the system holistically with regard to deadlocks, but the large number of possible actions would make the solution space extremely large and mean a considerable effort for the learning process. In this case it is also questionable whether a positive convergence of the learning curve would occur at all. This project therefore focuses on a multi-agent system and a sector-based approach. This does not rule out that new control architectures are discovered during the implementation that promote the learning behavior of the agents and are also used to answer the research questions.

The implementation section of the dissertation is divided into a deductive part, which implements application-oriented exemplary implementations of AI agents in deadlock-capable logistics systems, and an inductive part, which draws general theoretical conclusions from the simulation results on how to deal with deadlocks using machine learning methods. Figure 5 shows the structure of the planned implementation and which research questions need to be answered.

The primary and central goal of the dissertation is to make a fundamental contribution to the research of logistic deadlocks by taking up current technical developments in the field of machine learning in order to provide a better answer to avoiding and resolving deadlocks than previous approaches.

Secondary goals are the creation of insights into the learning behavior of the agents in deadlock-capable logistics systems (What are learning obstacles? What makes learning easier? How long do learning processes take?), a stronger and timely consideration of deadlocks in the planning process and a new strategy paradigm for dealing with deadlocks when applying machine learning methods.

5. Summary & Outlook

The consideration of deadlocks from a logistical perspective is a little researched area. The literature analysis that has already been carried out shows questions in this area of logistics planning in many places. The literature research and the preparation of research on deadlocks for logistics are already making an important contribution by identifying the planning phases of

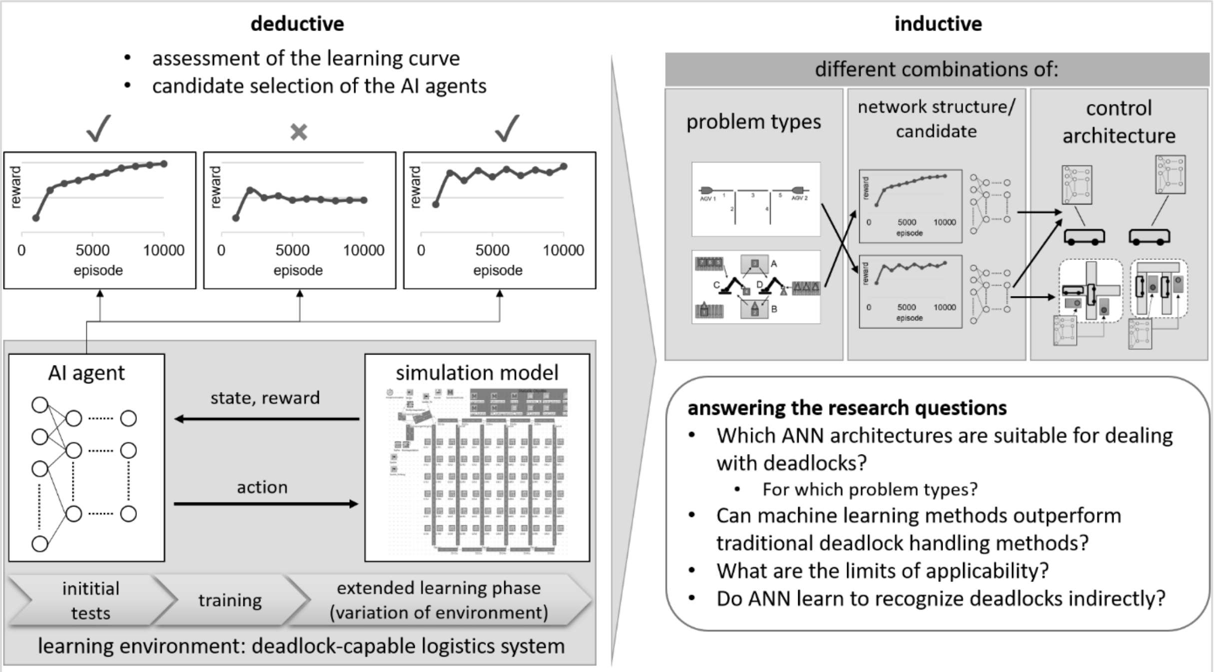

Figure 5: Structure of the planned implementation *within the dissertation*

logistics planning and problem types in logistics that are relevant for the consideration of deadlocks.

In the next step of the dissertation, the implementation structure described above will be implemented as a prototype. It should quickly become clear whether methods of reinforcement learning are even able to learn to make good decisions in more complex deadlock-capable systems according to the current state of technology and research. If the implementation is successful, statements can then be made about a suitable network structure, the location of the artificial intelligence and learning behavior.

References

[1] Kohl A-K, Pfretzschner F (2018) Logistikmonitor 2018: Ergebnisse einer Expertenbefragung von Statista und der Bundesvereinigung Logistik (BVL) e.V.

[2] Coffman EG, Elphick M, Shoshani A (1971) System Deadlocks. ACM Comput Surv 3:67–78. https://doi.org/10.1145/356586.356588

[3] Tanenbaum AS (2015) Modern operating systems, Fourth edition. Pearson, Boston

[4] Havender JW (1968) Avoiding deadlock in multitasking systems. IBM Syst J 7:74–84. https://doi.org/10.1147/sj.72.0074

[5] Holt RC (1972) Some Deadlock Properties of Computer Systems. ACM Comput Surv 4:179–196. https://doi.org/10.1145/356603.356607

[6] Palmer GI, Harper PR, Knight VA (2018) Modelling deadlock in open restricted queueing networks. European Journal of Operational Research 266:609–621. https://doi.org/10.1016/j.ejor.2017.10.039

[7] Bashir M, Liu D, Uzam M et al. (2018) Optimal enforcement of liveness to flexible manufacturing systems modeled with Petri nets via transition-based controllers. Advances in Mechanical Engineering 10:168781401775070. https://doi.org/10.1177/1687814017750707

[8] Zheng B, Lin C-W, Shiraishi S et al. (2020) Design and Analysis of Delay-Tolerant Intelligent Intersection Management. ACM Trans Cyber-Phys Syst 4:1–27. https://doi.org/10.1145/3300184

[9] Kuhn A, Bernemann S (eds) (1995) Prozessketten in der Logistik: Entwicklungstrends und Umsetzungsstrategien. Unternehmenslogistik. Verl. Praxiswissen, Dortmund

[10] VDI-Gesellschaft Fördertechnik Materialfluss Logistik (2002) Kommissioniersysteme: Systemfindung(3590)

[11] Gudehus T (2011) Logistik: Grundlagen - Strategien - Anwendungen, 4., aktualisierte Aufl 2010. Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg

[12] van Bonn B (2013) Basisdaten der Logistikplanung. In: Clausen U, Geiger C (eds) Verkehrs- und Transportlogistik. Springer Berlin Heidelberg, Berlin, Heidelberg, pp 291–298

[13] Mayer S, Furmans K (2010) Deadlock prevention in a completely decentralized controlled materials flow systems. Logist Res 2:147–158. https://doi.org/10.1007/s12159-010-0035-4

[14] Kim KH, Jeon SM, Ryu KR (2006) Deadlock prevention for automated guided vehicles in automated container terminals. OR Spectrum 28:659–679. https://doi.org/10.1007/s00291-006-0055-2
[15] Lienert T, Fottner J (2017) No More Deadlocks – Applying The Time Window Routing Method To Shuttle Systems. In: Paprika ZZ, Horák P, Váradi K et al. (eds) ECMS 2017 Proceedings edited by Zita Zoltay Paprika, Péter Horák, Kata Váradi, Péter Tamás Zwierczyk, Ágnes Vidovics-Dancs, János Péter Rádics. ECMS, pp 169–175
[16] Schönung F, Mayer S, Berbig D (2011) Dezentrale, deadlockfreie Steuerung eines Stetigförderers. at - Automatisierungstechnik 59:73. https://doi.org/10.1524/auto.2011.0914
[17] Seibold Z (2016) Logical time for decentralized control of material handling systems. Dissertation, Karlsruher Institut für Technologie (KIT)
[18] Forget P, D'Amours S, Frayret J-M et al. (2009) Study of the performance of multi-behaviour agents for supply chain planning. Computers in Industry 60:698–708. https://doi.org/10.1016/j.compind.2009.05.005
[19] Mors AWt (2010) The world according to MARP: Multi-Agent Route Planning. Technische Universiteit Delft, Delft
[20] Yalcin A (2017) Multi-Agent Route Planning in Grid-Based Storage Systems. Dissertation, Europa-Universität Viadrina Frankfurt
[21] Lu Z, Zhuang Z, Huang Z et al. (2019) A Framework of Multi-Agent Based Intelligent Production Logistics System. Procedia CIRP 83:557–562. https://doi.org/10.1016/j.procir.2019.04.116
[22] Mnih V, Kavukcuoglu K, Silver D et al. (2015) Human-level control through deep reinforcement learning. Nature 518:529–533. https://doi.org/10.1038/nature14236
[23] Bouderba SI, Moussa N (2019) Reinforcement Learning (Q-LEARNING) traffic light controller within intersection traffic system. In: Lazaar M, Duvallet C, Al Achhab M et al. (eds) Proceedings of the 4th International Conference on Big Data and Internet of Things. Association for Computing Machinery, New York, NY, USA, pp 1–6
[24] Bouton M, Nakhaei A, Fujimura K et al. (2019) Cooperation-Aware Reinforcement Learning for Merging in Dense Traffic. In: The 2019 IEEE Intelligent Transportation Systems Conference - ITSC: Auckland, New Zealand, 27-30 October 2019. IEEE, [Piscataway, New Jersey], pp 3441–3447
[25] Kujirai T, Yokota T (2019) Breaking Deadlocks in Multi-agent Reinforcement Learning with Sparse Interaction. In: Nayak AC, Sharma A (eds) PRICAI 2019: Trends in Artificial Intelligence, vol 11670. Springer International Publishing, Cham, pp 746–759
[26] Reijnen R, Zhang Y, Nuijten W et al. (2020) Combining Deep Reinforcement Learning with Search Heuristics for Solving Multi-Agent Path Finding in Segment-based Layouts. In: 2020 IEEE Symposium Series on Computational Intelligence (SSCI). Institute of Electrical and Electronics Engineers, Piscataway Township, New Jersey, US, pp 2647–2654
[27] Sørensen RA, Nielsen M, Karstoft H (2020) Routing in congested baggage handling systems using deep reinforcement learning. ICA 27:139–152. https://doi.org/10.3233/ICA-190613

Abstracting assembly processes on macro- and microscopic levels

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Abstract

In this contribution, the authors are discussing measures on the information content of a system model considering different abstraction levels. The idea is to make gains and losses of information between each level of abstraction visible. The levels of detail are aligned with existing concepts of macro- and microscopic modeling.
Representative approaches for each of these abstraction levels are applied to a basic model of an assembly line, from which estimates about the information content regarding widely used logistical Key Performance Indicators (KPI) of the respective model can be deducted.
In the example it is shown that a highly abstracted model can be used to gain a quick insight into interrelations in a system.

1. Introduction

In recent years modeling and simulation have become widely used methods of analysis. Especially in manufacturing systems, they are commonly used to get an insight into their behavior and to understand the dynamics of the underlying system. Because of its high adaptability, simulation enables the evaluation of different scenarios and system configurations [19].
The material flow in manufacturing systems is characterized by serial and parallel processes to manufacture specific products. Material flow systems are usually presented as a network to be able to offer the greatest possible degree of flexibility. These networks consist of subsystems and actors that enable processes to run in parallel as well as trigger interdependent processes. However, this leads to complex models that need to be investigated using adequate methods in order to control them. Material flow theory tries to find solutions to practical problems by applying qualitatively and quantitatively suitable modeling [12].
To contribute to this topic, this paper investigates the role of process abstraction at different levels in modeling an assembly process and discusses statements on the information content of Key Performance Indicators (KPIs) typically used in logistics analysis.
The remainder of the contribution is organized as follows. In a first step, the term process abstraction is discussed and how it can be adopted. The connection between the principles of proper modeling (PPM) and process abstraction is outlined and major approaches to modeling a basic assembly process are presented and applied. These are assigned to the macro- and microscopic abstraction levels.

2. Process Abstraction

Literature offers different classifications for the term model, according to the purpose of the model [7; 15], the method of analysis [19], or according to the form of description. They all have in common, the understanding that a model is a simplified representation of a real world system and that only details that are relevant to the purpose of the study should be represented. This simplification is crucial for the usability of the model [18].
In this paper, process abstraction is considered to provide a way to reduce the behavioral complexity of the model by reducing the variety of model components and their interactions. Abstraction is useful as long as the simulation results remain valid despite the reduction in complexity. In [4] it has been shown that abstract models are not only more easily understood, but also more straightforward to create and modify than non-abstracted models.

The approaches to abstracting a model can be divided into reduction, i.e. the deliberate omission of details, and idealization, i.e. the simplification of facts. However, the process of modeling is significantly influenced by the perception and experience of the modeler and represents an individual solution for a specific purpose [18]. Determining the level of abstraction is a crucial step in transforming real world observations into a model. Finding the "correct" level of abstraction often relates to addressing the appropriate amount of information to achieve the modeling objectives [20]. In Figure 1 the degree of abstraction is related to the respective amount of details and referred to as macro, meso, and micro level. At each level, characteristic problems and topics are addressed. At the micro level, the behavior of individual objects within a system is considered, this includes e.g. exact sizes and timings of these objects. Typically models of control systems, factory floors, warehouses, etc., that contain more details are assigned to this level. At the macro level aggregated values and global feedbacks are approached, e.g. the dynamics of ecosystems, business processes, and population developments. Generally, fewer details are needed to address topics at this level.

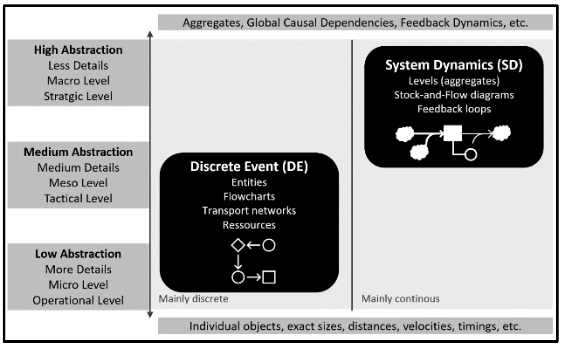

Figure 1: Modeling Approaches on Abstraction Levels (adapted from [6])

The same scale can be used to classify the main modeling approaches typically used to address specific problems at each level. Given the nature of these approaches, System Dynamics (SD) is used to provide an overview of the feedback structure of a system and can therefore be classified at the highest level of abstraction. The Discrete Event (DE) approach is typically used to examine individual objects at the lowest level of abstraction [6; 14; 4]. A closer look at the characteristics of these modeling approaches is taken in the next section.

For addressing topics assigned to the medium level of abstraction, e.g. planning tasks in logistics and production, [13; 14] recommend the use of the mesoscopic simulation approach. This discrete-rate-based approach provides an effective trade-off between fast model building and a tolerable degree of inaccuracy. However, to show the effect and specific usability of process abstraction, in the remainder modeling at the macro and micro level are considered and typically approaches are discussed.

In this paper, SD is referred to a high level of abstraction and DE to a low level of abstraction. However, this should not preclude the fact that different levels of abstraction can be addressed using one modeling approach. With some limitations, models at all levels of abstraction can be created using SD or DE.

Since typically in macro level modeling dynamics and interrelations in ecosystems are analyzed, this level is often considered as strategic level. The information gained through micro-level modeling can also support strategic decision making.

3. Basics of Modeling and Simulation in Logistics

To generate statements about the dynamics of a system, models based on mathematical and logical relationships are formulated and analyzed. However, when these analytical methods reach their limits, simulation is preferably used to analyze the system's behavior. Especially in logistics, numerous complex planning problems are predestined for the use of simulation. The possible applications range from modeling individual plants, assembly lines, or production processes to mapping entire transport systems and supply chains [17].

Models serve as the interface between requirements and their realization. Each model has a specific purpose. It depends on this purpose which parts of the original are relevant and are therefore represented, and which details are left out [19].

3.1. Principles of Proper Modeling (PPM)

In consideration of the importance of appropriate information modeling for the purpose of model use, it is necessary to ensure the quality and comparability of model development through criteria. Following the principles of proper accounting, the principles of proper modeling were formulated. They provide normative guidance to enable assessment of model quality, improvement of comparability, and integration. The following six factors also show interdependencies that need to be taken into account [7]:

- Principle of accuracy
- Principle of relevance
- Principle of economic efficiency
- Principle of clarity

- Principle of comparability
- Principle of systematic structure

The PPM reflect the minimum requirements concerning quality, clarity, and consistency. In line with these, models should be kept as simple as possible. Especially, the principle of economic efficiency, the principle of relevance, and the principle of clarity affirm this.
Accordingly, only aspects that are relevant to a defined modeling purpose and correspond to an underlying objective should be modeled. This can be concluded in the statement that a model should be created only as detailed as necessary [2; 3].
In addition, the principle of clarity describes the requirement to make models readable and understandable. Likewise, the application of a filter helps to highlight details that are relevant for the model user and to hide irrelevant ones [7]. In this way, modeling at different levels of abstraction can also be considered. By simplifying and reducing facts, information for decision makers can be provided in a selective way.
The explicit definition of the modeling purpose guides the selection of the level of abstraction and detail of the aspects to be modeled, as well as recommendations on which modeling approaches to use [8].

3.2. Modeling Approaches

One possible way of classifying system models is to distinguish between continuous and discrete-event models with respect to time and state [18]. Two major modeling approaches have been established: System Dynamics (SD) as a continuous approach and Discrete Event Simulation (DES) for the development of discrete-event models. The characteristics of these approaches are briefly explained below.

3.2.1. System Dynamics

System dynamics, evolving out of a field called industrial dynamics and firstly described by Jay W. Forrester in the late 1950s and early 1960s [10; 9] is a macro-level approach which mostly deals with modeling and simulation of complex systems. The complexity in the modeled systems is not defined solely by the number of elements or their highly interconnection, but more concrete by different facts which can be described with the term dynamic complexity. This includes basic features of real world systems, mainly pointing out the fact that everything is highly connected, actions taken from element “X” influence other elements which in the end leads to a change of the element “X” again. This is called a feedback loop and leads to a summation of little changes over time. The interconnected feedback loops describe the overall behavior of the system which might not be clear at the first sight. SD offers a possibility to model dynamic complex systems by determining the continous influences between elements and their reactions [22].
SD does not solely include the exploration of the systems elements and their influencing loops, but also tries to enable the transformation of the identified causal loops to a executable simulation model, where elements and their influences are represented as stocks and continous flows [21].

3.2.2. Discrete Event Simulation

In a Discrete Event Simulation (DES), with its basic ideas from Geoffrey Gordon in 1961 [1], the systems state is assumed to change just at specific, discrete events in time. Between the events the system state stays unchanged. The fact that changes happen only at events and not on entities’ purpose enables performant models where this type of description is sufficient. Modeling passive, non-self-determant actors as in DES is used in various scenarios in e.g. production or health care [6; 23].
Especially in production and logistics systems, DES is mostly the preferred modeling approach to show the behavior of production lines considering events and entities using certain resources. For analyzing the movement of the entities after each event in the simulation environment, queues are used to control the flow of objects. This is widely popular in e.g. assembly line simulation for modeling the flow of pieces through certain assembly stations [6].

4. Basic Model of an Assembly Process

In this section, an example of an assembly process is introduced and described. Furthermore, target values for the analysis and evaluation of a production system are defined, which can be used to describe the information contained in the underlying model.

4.1. Model Description

To demonstrate the application of the mentioned modeling approaches, a basic example of an assembly process was created. Figure 2 shows the schematic process consisting of:

- Preparation Process Step
- Assembly Line consisting of 5 individual stations
- Quality Check
- Final Machining

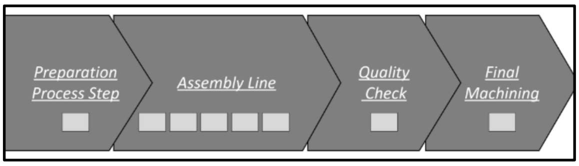

Figure 2: Schematic assembly process

Besides the process diagram, the following facts are known as input data:

- The batch sizes in which the parts are processed are 25 pieces in the Preparation Process Step and Assembly Line and 5 pieces in the Quality Check and Final Machining.
- The processing times of the Preparation Process Step, Quality Check, and Final Machining are 1 minute, 2 minutes, and 2 minutes respectively.
- The assembly line works in a tact time of 3 minutes.
- The transport between the workstations is carried out by employees.
- Availability of the units is assumed to be 100%.

4.2. Information Content

According to the PPM, specifically the principle of relevance, models are always deliberately abstracted from facts that are observable in this system but do not serve the purpose of the model [7]. By selecting the level of abstraction, decisions are made regarding the level of detail and the amount of information to be reflected in the model [20].
In this context, information is a rather broad term and has to be defined in a narrow sense for further discussion. In this paper, the focus lies on the information content concerning logistics aspects which can be extracted from the simulation runs. In the long term, information extraction is intended to determine whether the process meets the market requirements. To control the order flow in production processes, [5] defines a system of logistical quality characteristics. The deduction of KPIs from these characteristics, as well as their preparation and visualization, are well established in practice for the transparent evaluation of processes [11].

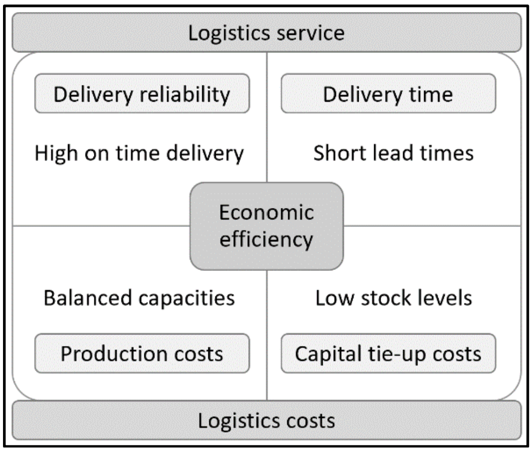

Figure 3: Objectives of production logistics after Wiendahl [5]

As shown in Figure3, in order to increase the efficiency of a production process, the logistics cost factor must be taken into account in addition to the logistics performance level. These are divided into four aspects: delivery reliability and delivery time are offset by production costs and capital tie-up costs.
To realize competitive logistics costs, the goal is to achieve a high level of capacity utilization and a reduction in inventories and work-in-process [11].

According to the in [5] proposed characteristics and KPIs the following were selected to address the information content in the basic model of an assembly process:

- Work in Process (WIP)
- Lead time
- Throughput
- Capacity Utilization

In this example of an assembly process, only the production steps are considered, thus sales orders are neglected and inventory levels are measured in terms of work in process.
Comparing the KPIs generated by the different modeling approaches, conclusions on the information value are drawn. Furthermore, the point of interest is to discuss the usability of process abstraction to enable an initial assessment of the real world system.

5. Changing the Level of Abstraction

Given the example of an assembly process, this section presents models of the proposed process at different levels of abstraction and discusses the evaluation of the KPIs defined in Section 4.2. The models are considered to be deterministic.

5.1. Microscopic Level

In section 2, the microscopic level was defined as the level with the highest information content and therefore holds the lowest degree of abstraction. Typically, assembly line systems at this level are modeled using the DE approach.

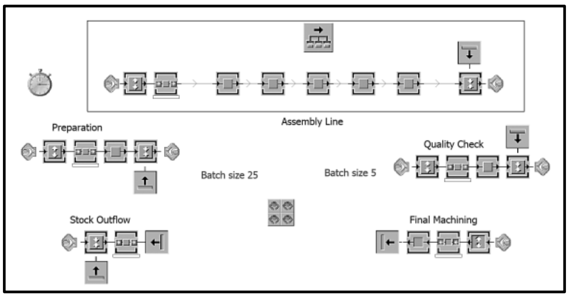

Figure 4: Model of the Assembly Process in PlantSimulation

In this contribution, the Tecnomatix Plant Simulation 15 application is used for modeling due to prior knowledge. Figure 4 shows the structure of the simulation according to the defined input data from section 4.1.
Based on a simulation time of 24 hours, the following values (Table 3) were calculated.

Table 3: Evaluation of KPIs microscopic level

Average WIP/h	77 pieces
Throughput	460 pieces
Lead Time	3:50:15 h
Capacity Utilization	67%

In the example process, an idealized value of 100% was assumed for availability. The high proportion of capacity utilization can be attributed to this circumstance; only waiting times between the process steps are taken into account.

5.2. Macroscopic Level

The macroscopic level was defined to hold the highest degree of abstraction and thus the lowest amount of details.
For the implementation of the SD approach, the program AnyLogic was chosen due to its wide range of applicability. The Stock and Flow Diagram in Figure 5 was designed for the representation of the basic assembly process.

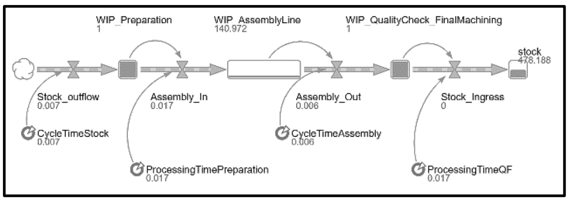

Figure 5: Stock and Flow Diagram in AnyLogic

The SD approach typically describes continuous flows. For this reason, the processing times and cycle times at the single stations had to be translated into rates. Further, the following simplifications and aggregations were made to display the assembly process as a Stock and Flow Diagram:

- Transport between the work stations is neglected.
- Front-end buffers and workstations were combined into one element.
- The 5 stations of the assembly line were abstracted to one element.
- The process steps Quality Check and Final Machining were aggregated into one element.

Based on a simulation time of 24 hours, the following values (Table 4) were calculated.

Table 4: Evaluation of KPIs macroscopic level

Average WIP/h	85 pieces
Throughput	478 pieces
Lead Time	7:03 min
Capacity utilization	--

Due to simplifications, deviations in the KPIs become clear in contrast to the DE model. These are small in terms of throughput and WIP. A strong deviation is evident in the lead time, which is caused by the fact that no batch sizes were modeled in the SD model. The continuous model also does not allow any statements to be made about the capacity utilization.

6. Discussion and Further Research

The choice of the appropriate level of abstraction and modeling approach is determined by the defined objectives, the purpose of the model, and the experience of the modeler. According to the principle of economic efficiency, a model should be as simple as possible in order to fulfill the model purpose.
In [2], the authors describe that an increase in the level of detail at the beginning of the model creation also leads to an increase in accuracy. After a certain point, however, this effect flattens out, with additional details no longer achieving a significant increase in accuracy. If the complexity is too high, a reduction in accuracy can also occur. Therefore, the approach recommended in [16] is to choose a high level of abstraction at the beginning of the model development and to gradually make the model as detailed as necessary for the model purpose. This can be achieved in a repeating process adding details and validating the model. It is important to be flexible to be able to quickly adapt the abstraction level of individual processes or the level of the entire model to new requirements.

In section 5, based on the same information about a basic model of an assembly process, the modeling approaches System Dynamics (SD) and Discrete Event Simulation (DES) were applied. The two approaches address different modeling purposes.
The DES approach is suitable for the modeling of logistics systems and thus, provides detailed information about batch sizes, throughput, lead time, buffer places etc. Using a DES approach, based on the model statements can be made about the capacity utilization of the system. Due to the high level of detail more effort is required in setting up the simulation model.
However, the SD model also provides answers to logistical questions. In the example above, it was shown that throughput, buffer sizes, and WIP can be determined using this model. It must be noted that due to simplifications at this level, KPIs are subject to higher uncertainty. Additional challenges exist in mapping a discrete manufacturing process to a continuous model. To achieve this, rates and conditions must be formulated that sufficiently describe the material flow.
Nevertheless, an SD model is mostly created more quickly and allows initial statements to be made about interrelations in the system. In the above example, initial conclusions can be made about possible bottlenecks and the development of the WIP. Based on these assessments, more detailed modeling and precise analyses can be applied.
This paper has provided a first insight into the information content and model use at the micro and macro levels of abstraction. For a deeper analysis, the model creation and discussion should be extended to the meso level and applied to a practical example. Additionally, research could be carried out on SD modeling at different levels of abstraction.

7. Conclusion

Most material flow systems are represented as a network to provide a high degree of flexibility, which leads to complex models that need to be investigated with adequate methods. In this contribution, the role of process abstraction in simulation modeling was discussed and modeling approaches on micro- and macroscopic levels were applied to a basic model of an assembly process. From this, statements were derived about the information content and the scope of application of the models.
Further research could be conducted to measure the accuracy of the models at different levels of abstraction and to present them in an industrial case study.

8. References

[1] Gordon, G.: A general purpose systems simulation program. In: Proceedings of the December 12-14, 1961, eastern joint computer conference: computers - key to total systems control on - AFIPS ‘61 (Eastern), pp.87–104.

[2] Robinson, S. (2010): Conceptual Modeling for Discrete-Event Simulation. Boca Raton, Fla.: CRC Press.

[3] Robinson, S. (2020): Conceptual modelling for simulation: Progress and grand challenges. Journal of Simulation 1, pp.1–20.

[4] Brailsford, S. C.; Churilov, L.; Dangerfield, B. (Hg.) (2014): Discrete-Event Simulation and System Dynamics for Management Decision Making. Chichester: John Wiley & Sons.

[5] Wiendahl, H.-P. (Hg.) (2002): Erfolgsfaktor Logistikqualität. Vorgehen, Methoden und Werkzeuge zur Verbesserung der Logistikleistung. Berlin: Springer.

[6] Borshchev, A.; Filippov, A. (2004): From System Dynamics and Discrete Event to Practical Agent Based Modeling: Reasons, Techniques, Tools. In: Proceedings of the 22nd International Conference of the System Dynamics Society. Oxford.

[7] Becker, J.; Probandt, W.; Vering, O. (Hg.) (2012): Grundsätze ordnungsmäßiger Modellierung. Berlin, Heidelberg: Springer Berlin Heidelberg.

[8] Schütte, R. (1998): Grundsätze ordnungsmäßiger Referenzmodellierung. Konstruktion konfigurations- und anpassungsorientierter Modelle. Wiesbaden, s.l.: Gabler Verlag.

[9] Forrester, J. (1961): Industrial Dynamics. MIT Press.

[10]Forrester, J. (1958): Industrial Dynamics: A Major Breakthrough for Decision Makers. Harvard Business Review Vol. 36, No. 4, pp.37–66.

[11] Nyhuis, P.; Wiendahl, H.-P. (2012): Logistische Kennlinien. Grundlagen, Werkzeuge und Anwendungen. 3. Aufl. 2012. Berlin, Heidelberg: Springer.

[12] Arnold, D.; Furmans, K. (2009): Materialfluss in Logistiksystemen. 6., erweiterte Aufl. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

[13] Reggelin, T.; Lang, S.; Schauf, C. (2020): Mesoscopic discrete-rate-based simulation models for production and logistics planning. Journal of Simulation, pp.1–10.

[14] Schenk, M.; Tolujew, J.; Reggelin, T. (2009): Mesoscopic Modeling and Simulation of Logistics Networks. IFAC Proceedings Volumes 4, pp.582–587.

[15] Banks, C. M.; Sokolowski, J. A. (2009): Principles of modeling and simulation. A

multidisciplinary approach. Hoboken, N.J: John Wiley.
[16] Vasudevan, K.; Devikar, A. (2011): Selecting Simulation Abstraction Levels in Simulation Models of Complex Manufacturing Systems. In: Proceedings of the 2011 Winter Simulation Conference (WSC). Phoenix, AZ, USA, pp.2268–2277.
[17] Eley, M. (2012): Simulation in der Logistik. Einführung in die Erstellung ereignisdiskreter Modelle unter Verwendung des Werkzeuges „Plant Simulation“. Berlin, Heidelberg: Springer Berlin Heidelberg.
[18] Gutenschwager, K.; Rabe, M.; Spieckermann, S.; Wenzel, S. (2017): Simulation in Produktion und Logistik. Grundlagen und Anwendungen. Berlin: Springer Vieweg.
[19] Law, A. M. (2015): Simulation Modeling and Analysis. 5. ed. New York, NY: McGraw-Hill Education.
[20] Benjamin, P.; Erraguntla, M.; Delen, D.; Mayer, R. (1998): Simulation Modeling at Multiple Levels of Abstraction. In: Proceedings of the 1998 Winter Simulation Conference. Washington, DC, pp.391–398.
[21] Sterman, J. D. (2001): System Dynamics Modeling: Tools for Learning in a Complex World. California Management Review Vol 43, No.4, pp.8–25.
[22] Sterman, J. D. (2002): System Dynamics: Systems Thinking and Modeling for a Complex World. In: ESD Internal Symposium. Massachusetts, pp.1–29.
[23] Furian, N.; Neubacher, D.; Vössner, S.; O’Sullivan, M.; Walker, C. (2014): Towards Holistic Modeling and Simulation of Discrete Event and Individual Based Behavior. In: Proceedings of the European Simulation and Modelling Conference. Porto.

Tool storage and delivery in flexible manufacturing

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Abstract
Flexible manufacturing of body parts of aircraft engine and pumping systems is characterized by a large number of surfaces which can be made by use of the corresponding number of cutting tools. The tendency to the diversification of the production at the highest utilization of the CNC units results in widening of the nomenclature of the produced workpieces and just increases the number of the engaged tools. A complex system of the tool storage and delivery should be designed in this case, and a number of subsystems incorporated into the process complicate the estimation of productivity of the whole system. The queuing theory allows solving the problem of calculation of the tool storage and delivery system capacity.

9. Introduction
Modern flexible machining enterprise appears in different forms which depend on the variety of types of workpieces produced for a certain period (typically, for a month). At that, flexible manufacturing lines and cell-type systems united in workshops can be distinguished. The main problems with respect to the tool backup of the manufacturing concerns the cell-type FMS. The variety of the workpieces produced in automation lines, which correspond to the large batch production, is relatively small. Thus, the capacity of the CNC machine-bound tool magazines can be fit to the number of the tools necessary to machine the whole nomenclature of the workpieces, and the system can operate without regarding the need for the tool supply during the production cycle. In the opposite end, the cell-type flexible manufacturing units (FMU) based on CNC machines handled by human operators are implemented in small batch production, and the operators can change the tools at the necessity by relying on the own experience.
A concept of the cell-type FMS provided with the relatively large storage systems of high capacity exists in the middle between the described types of the flexible manufacturing. These storage systems are arranged directly in the production area and necessary to ensure the prompt delivery of tools to the CNC units. The tool delivery is conducted by use of movable automated operators thus connecting the CNC machine-bound tool magazines with the central tool storage, which allows preventing the interference of the production units with a human operator.
However, a number of problems emerge at the attempt to implement the concept. The number of tools to machine the whole nomenclature can be rather big, especially for the case-shaped body parts with the large diversity of orifices and manufacturing tolerances. At that a task of scheduling the traffic of the tool operators between the CNC machines and central tool storage under a condition of limited traffic capacity should be solved. The task is complicated by the demands made by an adjacent assembling manufacturing as well as particular demands of the parts machining.
A planning of such systems is not an ordinary task [1]. Various methods can be applied to solve the problem; however, a combination of expert judgments powered by the mathematical methods

such as queuing theory [2] and numerical simulation [3] looks as the most reliable. The queuing theory proved its effectiveness since the early analysis of the flow-type manufacturing systems using the cyclic queuing theory conducted by Hitomi et al. [4], and later was successfully applied to simulation of flexible manufacturing systems (FMS) [5], to industry applications [6, 7, 8] and production-inventory optimization [9]. However, the problems discussed in the cited literature are dedicated to application of the queuing theory to analyze the choice of various concepts of manufacturing. Indeed, a layout of the whole plant with the conclusion about the beneficial points of functional or cellular layouts of machines for flow line, medium demand, and low product volume environment was discussed by Wainwright [7]. Queuing analysis was applied to estimate a multi-stage production (flow) line with respect to utilization, percentage of idle workstation, number of batches in system, number of batches in queue, expected time spent in queue, and expected time spent in system, as was reported by Marsudi and Shafeek [8]. An approach to describe the operation of multi-functional machines united together by a flexible manufacturing system (FMS) was made by Jain *et al.* [10]. In contrast, a systematic in-depth investigation of a particular type of FMS, namely a cell-type system of the multi-functional machines is conducted in our work. General approach of the queuing theory consists in treating a system as a set of servers with a queue where the handled objects are stored if the servers are occupied in the production process. It was applied to calculate the productivity of the workpieces storage and delivery system in flexible production [11]. This approach is also used in the present work to analyze the capacity of the tool storage and delivery system of a FMS composed of CNC machines to produce hi-tech equipment for the needs of a modern aircraft industry. The system includes a central tool storage which is a construction where the fully assembled cutting tools are stored in close proximity to the CNC machines, transfer lines to deliver the tools to the CNC units, and serving robots.

10. Methods

A flexible manufacturing workshop considered in the paper, is shown in Figure 1. It includes N_{cu} CNC machines provided with the machine-bound buffer magazines of a specified capacity, and produces a certain number of workpieces of a wide nomenclature.

A lot of different tools N_{tools} (items) should be engaged to complete the task during a month and the total capacity of the machine-bound magazines cannot accommodate the whole number of the tools. At the same time, the tool delivery from the workshop tool storage by use of the workshop transport is also not a case due to non-flexibility and slowness of the process. Thus, central tool storage is mounted at some height (approximately at about 2 m) directly in the flexible manufacturing

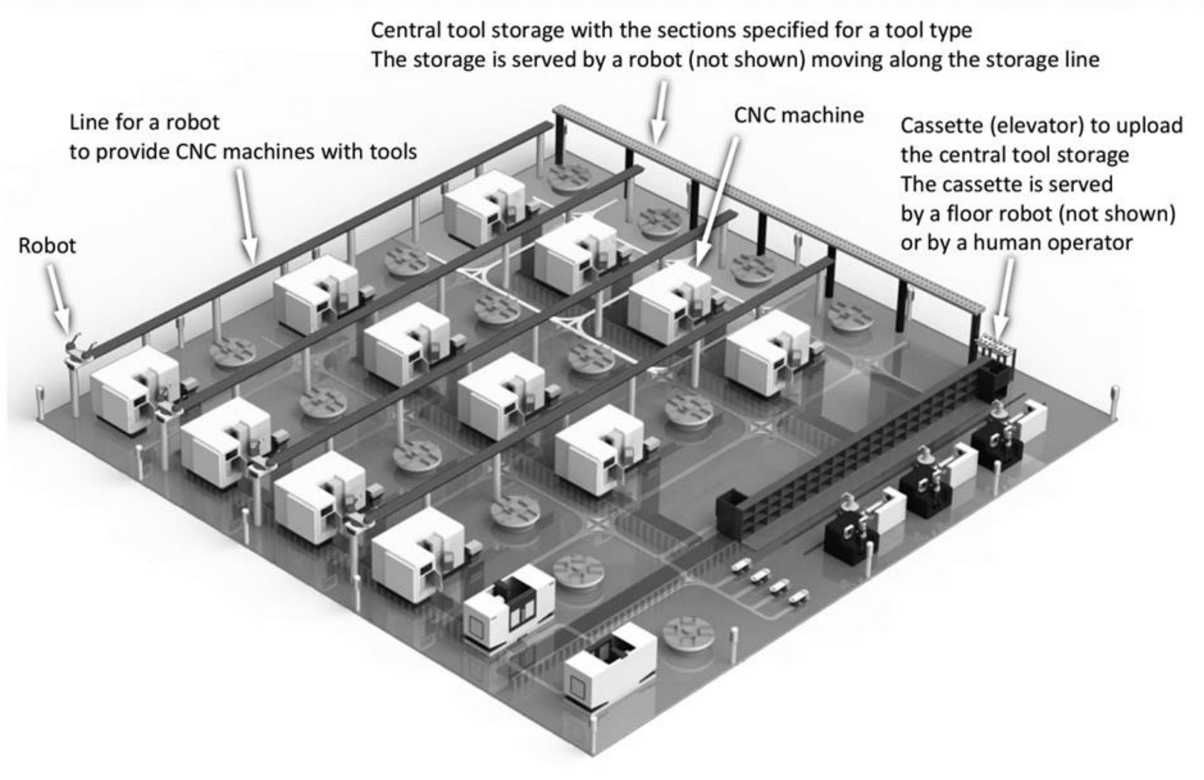

Figure 1: General view of machining flexible manufacturing system (FMS) with the central tool storage and lines for robots to provide CNC machines with tools, which is considered in the paper

workshop. By the structure, the tool storage is of a linear type with a number of cells made in the body of the storage. The whole number of the cells is divided onto the sections responsible for the storage of a certain type of the tool, and each of the sections contains m_c number cells, which is a subject of the calculations performed below. This central tool storage is serviced by a robot that is moving along the storage line. To deliver the tools to the robot, an elevator is used. At the highest point, the elevator is a part of the storage, while at the lowest point it can be serviced by a workshop transport robot, or by a human operator. In a case when all the cells specified for a certain tool type, are already occupied, the tool cannot be accepted from the elevator and stored in the central storage.

The servicing robot can deliver a tool required by a certain CNC machine, to one of n_l tool transfer lines which, in turn, are serviced by their own robots. Again, if all of the transfer lines are occupied by the transport operations, the required tool cannot be delivered to the CNC machine, thus, the number n_l should also be calculated to meet the production rate.

Hence, the whole task includes the calculations of the necessary capacity of the sections of the central tool storage, and the number of lines to transfer the tools to the CNC machine-bound buffer magazines. It should be mentioned that the structure of the magazines must allow interchanging the tools by use of the transfer line robot.

In terms of the queuing theory, all robots of the tool storage and transfer lines are considered as servers, which deal with a flow of the tools arriving at a rate λ (tools/h). At the same time, each robot is characterized by the service rate μ (tools/h). These two parameters allow calculating the utilization factor:

$$\alpha = \frac{\lambda}{\mu}. \qquad (1)$$

10.1. Calculation of the number of lines for robots to provide CNC machines with tools

To calculate the tool arrival rate λ, the total number of tools N_{tools} and the production resource Φ_0 per month are considered:

$$\lambda = \frac{N_{tools}}{\Phi_0}. \qquad (2)$$

Average duration of the transport operation performed by a robot in the tool transfer line takes into account the total length of the line of the CNC machines, which is a product of the number N_{cu} of the CNC machines and their dimension L_{cu} (m), number n_l of the tool transfer lines, speed V_{ao} of the robot movement (m/min), and the duration t_{ao0} (min) of the tool manipulation procedure performed by the robot at the end points of the line:

$$t_{ao} = \frac{N_{cu}L_{cu}}{60\mathrm{n}_l V_{ao}} + \frac{t_{ao0}}{60}. \qquad (3)$$

Thus, the service rate per unit time for one robot is:

$$\mu = \frac{1}{t_{ao}}, \qquad (4)$$

and the utilization factor α can be calculated by use of expression (1).

The transfer system consisting of the transport robots and the lines for the robots to provide the CNC machines with the cutting tools was considered as a multi-server system with no queue. Under the assumption, the tool appointed to be transferred for the machining can be serviced by the robotic line only if at least one robot is not occupied for transportation of the tools. In this case, the normalization constant describing the probability that all the robots are free, is:

$$p_0 = \left(\sum_{i=0}^{n_l} \frac{\alpha^i}{i!}\right)^{-1}. \qquad (5)$$

A probability that i number of the robotic lines is occupied:

$$p_i = \frac{\alpha^i}{i!} p_0. \qquad (6)$$

A probability that a tool cannot be serviced (rejection probability) equals to the probability p_{nl}, where n_l is the number of the lines for the tool transfer:

$$p_{rej} = p_{n_l} = \frac{\alpha^{n_l}}{n_l!} p_0. \qquad (7)$$

Relative service capacity of the system is

$$q = 1 - p_{rej}. \qquad (8)$$

Absolute service capacity is:

$$A = q\lambda. \qquad (9)$$

Average number of the robotic lines engaged into the transportation is:

$$K_m = \sum_{i=0}^{m-1} i p_i + \sum_{r=0}^{n} m p_{m+r}, \qquad (10)$$

and the utilization of the robotic lines for the tool transfer is:

$$K_{pu} = \frac{A}{\mu}. \quad (11)$$

A search for the number of transfer lines is finished when the rejection probability reaches a specified value (usually of a few percent).

10.2. Calculation of the capacity of a section in the central tool storage

The central tool storage consists of a number of sells divided into the sections, where each section is tailored for a certain type of the cutting tool. To calculate the number of the cells in a section, the whole system of the linear-type storage with a servicing robot is considered as a single-server system with the limited queue. The tools are delivered by the servicing robot to the transport lines considered in the previous section. The tool storage and delivery are rejected in this central storage if all the cells of a section associated with the certain type of the tool are occupied.
The tool arrival rate λ, the service rate μ per unit time, and the utilization factor α can be calculated by use of expressions (1), (2), and (4).
The probability that the servicing robot is occupied but a section is completely free from the tool specified for the section is:

$$p_0 = \begin{cases} \frac{1-\alpha}{1-\alpha^{m_c+2}}, & \alpha \neq 1, \\ \frac{1}{m_c+2}, & \alpha = 1, \end{cases} \quad (12)$$

while the probabilities that the robot is occupied and 1, 2, …, *i*, …, m_c tools are already located in the section are:

$$p_i = \alpha^i p_0, \; i = 1,2,\dots, \; m_c + 1. \quad (13)$$

The rejection probability is

$$p_{rej} = p_{m_c+1}. \quad (14)$$

Relative and absolute service capacities of a section are calculated by use of formulas (8) and (9).
An average number of the cells occupied by the tools of a certain type is

$$N_{st-av} = \begin{cases} \frac{\alpha^2[1-\alpha^{m_c}(m_c+1-m_c\alpha)]}{(1-\alpha^{m_c+2})(1-\alpha)}, & \alpha \neq 1, \\ \frac{m_c(m_c+1)}{2(m_c+2)}, & \alpha = 1. \end{cases} \quad (15)$$

An average number of the tools serviced by the robot and stored in the certain section is

$$N_{t-av} = N_{st-av} + 1 - p_0. \quad (16)$$

The average time of storage for the tools is

$$t_{stor} = \frac{N_{st-av}}{\lambda}, \quad (17)$$

while the average time of servicing is

$$t_{serv} = \frac{N_{st-av}}{\lambda} + \frac{q}{\mu}. \quad (18)$$

Cell utilization is described by the expression:

$$K_{cu} = \frac{N_{st-av}}{m_c}. \quad (19)$$

11. Results of calculations

The developed model was applied to calculate the tool transfer and storage system of the flexible manufacturing system shown in Figure 1. At that the following parameters of the model are used: N_{cu} = 12, L_{cu} = 5 m, N_{tools} = 6700 items, Φ_0 = 305 h, t_{ao0} = 2 minutes for the robots of the tool transfer lines and t_{ao0} = 0.5 minutes for the robot of the central tool storage. Then the main characteristics of the server systems were calculated by use of the expressions (1)-(4); the tool arrival rate λ is 21.967 items/h.
The results of the calculations of the rejection probability in the multi-server system with no queue, which is composed of the transfer lines with robots, expression (7), at a dependence on the number of the number of the lines, is shown in Figure 2.

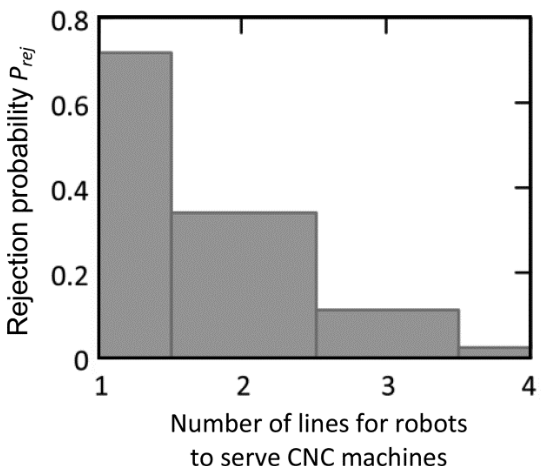

Figure 2: Dependence of the rejection probability on the number of lines for robots to serve CNC machines

As it can be seen, the rejection probability is decreased from as high as 0.72 for n_l = 1 (one line with a robot serves the whole set of the CNC units) to 0.026 for n_l = 4 (or three CNC machine per one line). As a result, the absolute service capacity (9) increases from 6.2 tools/h to 21.4 tools/h, Ref. Figure 3.

It is noteworthy that a direct approach, when the total service rate μ (which is dependent in this case on the number of the lines) of the transfer lines is just equal to the tool arrival rate λ (it can be obtained for $n_l = 2$), will result in the absolute service capacity of about 14.56 tools/h, which is far from the necessary productivity of the FMS described by λ. At the same time, the utilization (11) of the transfer line robots is decreased from 0.791 to 0.29, as it is shown in Figure 4.

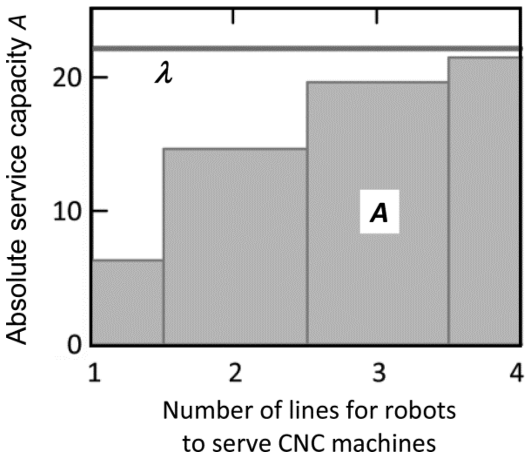

Figure 3: Dependence of the absolute service capacity on the number of lines for robots to provide CNC machines with tools

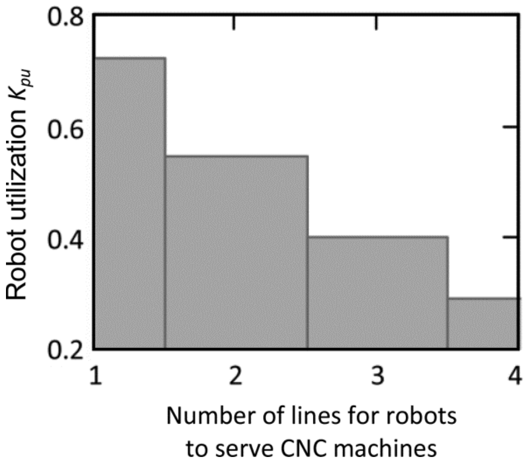

Figure 4: Dependence of the CNC machine utilization on the number of lines for robots to provide CNC machines with tools

The central tool storage is divided into the sections according to the variety of the specialized tools determined by the nomenclature of the workpieces. Direct approach assumes that each of the section should be equipped with just one cell for the corresponding type of tools. However, the calculations confirm that in this case the productivity of FMS will be decreased just because of the rejections for service for the tools delivered from the workshop tool storage. The results shown in Figure 5 confirm that the rejection probability (14) decreases from 0.18 to 0.0053, when the number of the cells is increased from 1 to 3 in each section.

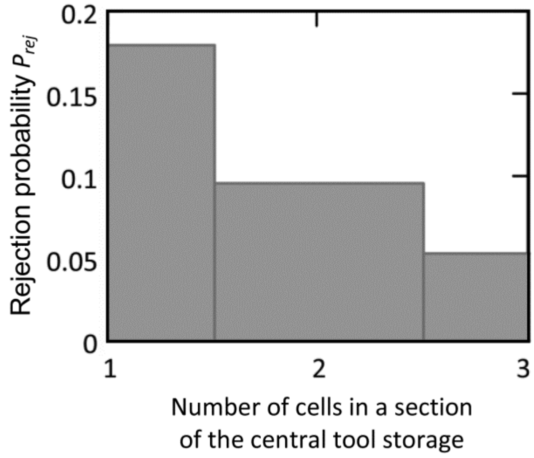

Figure 5: Dependence of the rejection probability on the number of cells in a section of the central tool storage

As a result, the absolute service capacity of each section is increased from 18 items/h to 20.793 items/h, Ref. Figure 6.

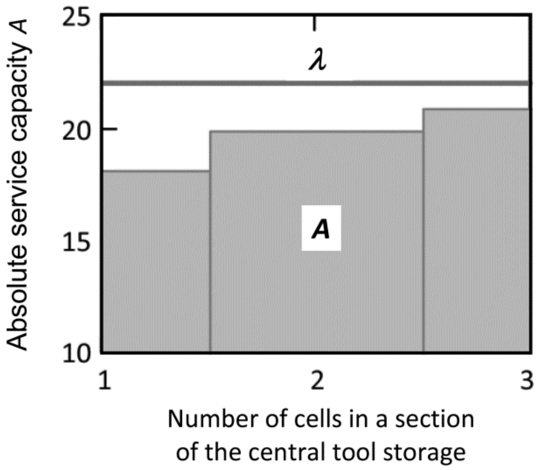

Figure 6: Dependence of the absolute service capacity on the number of cells in a section of the central tool storage

In this case the number of cells in the section is increased, which results in decreasing the cells utilization (19) from 0.18 to 0.165, Ref. Figure 7. It should be noted that both of the calculated server systems compose a series chain in the tool delivery, and the total service probability is a product of a kind

$$P_{serv} = \prod_{i=1}^{k}\left(1 - p_{rej(i)}\right), \quad (20)$$

where $p_{rej(i)}$ is a rejection probability of i^{th} system in the chain. Thus, all the systems should be calculated to estimate the real productively of FMS.

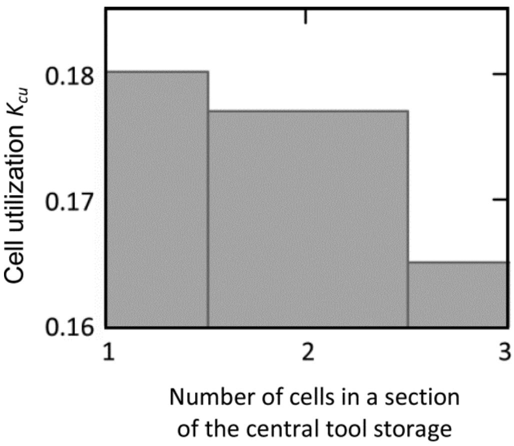

Figure 7: Dependence of the cell utilization on the number of cells in a section of the central tool storage

12. Summary

Application of queuing theory to the problems of flexible manufacturing allows estimating correctly the productivity of the system by considering the effectiveness of the incorporated subsystems. Large nomenclature of workpieces demands large number of cutting tools which cannot be stored in the machine-bound tool magazines. To solve the problem, a tool delivery and storage system composed of central tool storage and transfer lines serviced by robots should be implemented. The queuing theory allows calculating the number of cells of the storage as well as the number of the transfer lines to satisfy the design capacity of the workshop. Elimination of this theory and use of the direct approach based on the average parameters of the manufacturing process results in almost two-fold decrease of the productivity.
In future, the methods of the queuing theory are planned to be applied to formulate and solve the problem for calculating the material flows of a workshop storage that services the discussed type of FMS.

13. References

[1] Schenk, M.; Wirth, S.; Müller, E. (2010): Factory Planning Manual – Simulation-Driven Production Facility Planning. Berlin, Heidelberg, London: Springer Verlag, 405 p.

[2] Govil M. K.; Fu M. C. (1999): Queueing Theory in Manufacturing: A Survey. Journal of Manufacturing Systems 18:3.

[3] Schenk, M.; Wirth, S.; Müller, E. (2010): Object Oriented Simulation – A Modeling and Programming Perspective. London: Springer Verlag, 450 p.

[4] Hitomi K.; Nakajima M.; Osaka Y. (1978): Analysis of the Flow-Type Manufacturing Systems Using the Cyclic Queuing Theory. Journal of Engineering for Industry 100(4):468-474.

[5] Ullah, H. (2011): Petri net versus queuing theory for evaluation of FMS. Assembly Automation 31 (1): 29-37.

[6] Bhat, U. N. (2015): An Introduction to Queueing Theory, Statistics for Industry and Technology. Boston MA, Birkhäuser.

[7] Wainwright, C. (1996): The application of queuing theory in the analysis of plant layout. International Journal of Operations & Production Management 16 (1):50-74.

[8] Marsudi, M.; Shafeek, H. (2014): The Application of Queuing Theory in Multi-Stage Production Line. In: Proceedings of the International Conference on Industrial Engineering and Operations Management. Bali, Indonesia, pp. 668-675.

[9] Rashid, R.; Hoseini, S. F.; Gholamian, M. R.; Feizabadi, M. (2015): Application of queuing theory in production-inventory Optimization. Journal of Industrial Engineering International 11:485–494.

[10] Jain, M.; Maheshwari, S.; Baghel, K.P.S. (2008): Queueing network modelling of flexible manufacturing system using mean value analysis. Applied Mathematical Modelling 32:700–711.

[11] Serdiuk, O.; Baranov, O; Rudenko, N. (2020): Application of queuing theory in development of storage system of flexible manufacturing. In: Proceedings of the 13th International Doctoral Students Workshop on Logistics. Otto-von-Guericke-University Magdeburg, pp. 91-96.

Participating Universities

Otto von Guericke University Magdeburg

The Otto von Guericke University (OVGU) was founded in 1993 from three institutions of higher education: the Technical University Magdeburg, the Teacher Training College and the Medical Academy of Magdeburg. It is named after the famous scientist Otto von Guericke, whose research on the vacuum, especially his hemispheres experiment, earned him fame beyond German borders.

Consisting of 9 Faculties, OVGU offers more than 100 academic programs. 13500 students are enrolled at OVGU; 3500 of them are international students. OVGU is one of Germany’s youngest universities. Its innovative fundamental research contributes to the city’s and the country’s social and scientific development.

The Institute of Logistics and Material Handling Systems is part of the Faculty of Mechanical Engineering and looks back on more than 60 years of experience in training and research in the field of conveying technologies, logistics and material handling systems.

The fields of research include:

- Mathematical modeling and simulation,
- Development of instruments for analysis and planning,
- The conservation of resources, energy efficiency and sustainable logistics,
- Discrete element method simulation in continuous conveying technology,
- Virtual engineering,
- Ramp-up management and
- The transfer of methodology and know-how in logistics.

www.ilm.ovgu.de

Universidad Central “Marta Abreu” de Las Villas

The Universidad Central »Marta Abreu« de Las Villas (UCLV) was founded in 1948 in Santa Clara. Approximately 9500 students are enrolled at the university, which consists of 12 faculties. The green, spacious campus is located on the outskirts and makes up its own small student town that could be reached by car, bus or train. UCLV is the third-biggest university of Cuba. It has ranked on top places in all national evaluations of the quality of teaching and research. UCLV is part of several national and international research networks and has scientific cooperation with 130 institutions around the world. Intensive collaboration with the OVGU in Magdeburg focuses on the departments of manufacturing, engineering and quality management, mechanics, construction, computer science, automotive technology, process and environmental technologies and especially logistics and material handling systems.
In 2016, the university immersed in an integration process where industrial engineering and mechanical engineering came together in a single faculty named Faculty of Mechanical and Industrial Engineering.
Of the 90 teachers of the faculty, 60% have a Doctorate in a specific science, while 70% have already reached a higher teaching category. The faculty has two teaching departments (Mechanical Engineering and Industrial Engineering), two Study Centers (Center for Energy Studies and Environmental Technologies, Welding Research Center)
The Department of Mechanical Engineering most important fields of research pertaining to logistics and material handling systems are:
Technical logistics,
Quality management, quality engineering, metrology, measurement uncertainty
Manufacturing (manufacturing engineering and welding technology),
Environmental technology.
Furthermore, researches conducted in the fields of biomechanics, mechatronics, development and construction.
The central fields of research pertaining to logistics and material handling systems at the Department of Industrial Engineering are:
Quality management, quality engineering,
Mathematical statistics, operations research, design of experiments, statistical simulation,
Reliability and safety,
Logistical networks.

www.uclv.edu.cu

National Aerospace University “KhAI”

National Aerospace University, Kharkiv, Ukraine (KhAI) was established in 1930. Its history is closely connected with the development of aircraft engineering and science. The University is well-known for its achievements in aviation industry, namely for the creation of the first European high-speed airplane with a retractable landing gear and the design of the turbojet engine. At present about 9.5 ths students and 160 post-graduate students are trained at the University; 650 teachers and 2.5 ths employers work here. Among them there are 120 Professors and PhD. This makes KhAI one of the leading institutions of higher education in that trains specialists for aerospace industry in Ukraine and abroad. During the period of its existence the University has trained about 80 ths engineers. More than 80 % of the experts with higher education who work in Ukrainian aerospace area are the graduates of the NAU KhAI.

The NAU KhAI is a member of International Association of Universities, EASN, PEGASUS organizations as well as is a signatory of Magna Charta Universitatum. Together with European partners it received the highest number in Ukraine of scientific and educational grants TEMPUS FP-7 and the European Union. The NAU KhAI is a co-executor of many scientific and educational programs which are carried out with universities and companies of EU, Mexico, China.

In 1994 KhAI signed a partnership agreement with OvGU, thus setting new joint educational and research tasks in aircraft design, composite component design, technologies for rapid processing of steel structures etc.

National Aerospace University is persistent in raising its bar, being always ready to welcome and support students and young researchers from all over the world. Now the university trains more than 1,400 foreign students from 45 countries on different directions

https://khai.edu/en/university/

University of Miskolc

The history of the University of Miskolc refers to Mining and Metallurgy back in 1735. Since those times, the organization of the University changed and was extended several times with new faculties, now being named since 1990 the University of Miskolc. While technical education has the longest tradition at the University of Miskolc, during the recent decades the institution was transformed into a true university. Currently it has eight distinct faculties. At present, faculties have more than 8000 students, who are assisted in their academic advancement by an educational staff of more than 550 and a non-educational staff of more than 650 members.

On most faculties, B.Sc. and M.Sc. programs are both offered for the students. The University of Miskolc started Ph.D. programs on the basis of accredited doctoral programs on October 1, 1993. Currently six Faculties of the University offer doctoral programs and award Ph.D. degrees in seven disciplines: Earth Science, Materials Science and Technologies, Engineering Science, Information Science, Law, Economics and Management Science, Literary Studies.

The University of Miskolc is the largest higher education institution in Northern Hungary. With its highly qualified experts, instrument infrastructure and laboratories, it contributes to scientific research and technical development in Hungary.

The Institute of Logistics is part of the Faculty of Mechanical Engineering and Informatics. The Institute has a wide range of educational activities at 3 Faculties of the University of Miskolc in the frame of full time and part time trainings. The focus of research activities of the institute lies in the following fields:

- Design of materials handling machines,
- Controlling and planning methods for modular materials handling systems,
- Computer integrated logistics, information logistics,
- Production and service logistics,
- Warehouse logistics, stock management,
- Recycling logistics,
- Maintenance and Quality assurance logistics,
- Optimization of complex logistics systems,
- Simulation-based process improvement,
- Global logistics, supply and distribution systems,
- Industry 4.0 and logistics,
- Lean logistics.

www.uni-miskolc.hu

University of Technology of Troyes

The University of Technology of Troyes (UTT) has as mission, research, training and technology transfer. A public institution created in Troyes in 1994, UTT is now one of the 10 most important engineering schools in France and it trains more than 3100 students each year.
The UTT relies on its 8 research teams to offer courses covering the entire university spectrum: Bachelor's, Master's, Engineering and Ph.D., short professionalizing courses, specialized Master's programs, validation of acquired experience and language certifications.
The UTT values student initiative, commitment and entrepreneurship as an integral part of the training of women and men ready to imagine the future, to manage complexity, to adapt to change while mobilizing advanced scientific and technological skills.
The design and manufacture of new materials, the intelligence of objects and robotics, information systems transformed by artificial intelligence, cybersecurity, new management methods, open innovation, and collective intelligence are just some of the topics that are covered by the UTT's research, training, and technology transfer activities, which are structured around 10 areas of expertise:

- Networks, people and objects, connected
- Circular economy and sustainability
- Nanotechnologies and functional materials
- Logistics and production of the future
- Silver technologies
- Mechanical design and virtual reality
- Innovative materials and manufacturing processes
- Safety and risk management
- Use and design of digital technologies

www.utt.fr

Montanuniversitaet Leoben

Founded in 1840, as a technical university with a unique profile, Montanuniversitaet Leoben claims a special position in both the Austrian and international academic landscape. The research profile of the Montanuniversitaet Leoben is based on the value-added lifecycle, starting with the exploration and extraction of raw materials, followed by fields such as metallurgy, high-performance materials, process and production engineering, and complemented by environmental engineering and recycling. The research agenda of Montanuniversitaet Leoben is focused on three areas of expertise, i.e., advanced resources, smart materials and sustainable processing. The range of disciplines is complemented by multidisciplinary fields such as Industrial Energy Technology and Industrial Logistics.

The Chair of Industrial Logistics was founded in 2003. Industrial Logistics represents the link between procurement markets (suppliers), production facilities (plants) and sales markets (customers), across multi-tier supply chains. Challenges lie in the management of increasing complexity, volatility and risk of global business activities, and the application of analytical methods to create added value from data.

Research focuses on logistics systems design and engineering, for manufacturing companies and industrial supply chains, aiming to improve visibility, material flows, flexibility, performance and economics.

The focus of the Chair of Industrial Logistics in education is:

- Supply chain strategy
- Logistics systems planning and design
- Design and optimization of industrial material and information flows
- Production planning and control
- Process management in production systems
- Warehouse and transport organization
- Management of complexity and risk

www.unileoben.ac.at

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