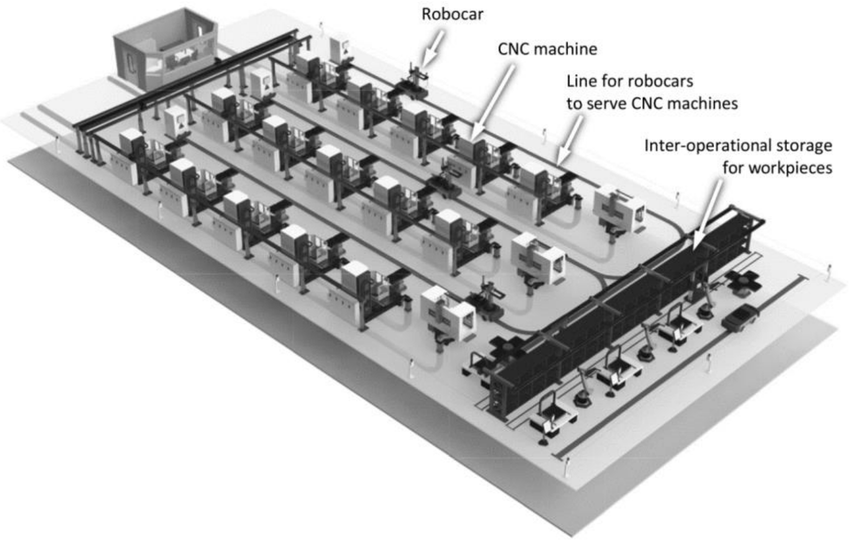


# 15th International Doctoral Students Workshop on Logistics

23 June 2022, Magdeburg

Institute of Logistics and Material Handling Systems

Conference Proceedings

OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

# 15th International Doctoral Students Workshop on Logistics

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# Foreword

Dear Ladies and Gentlemen,
Colleagues and Friends,

We are pleased to present the proceedings of our 15th International Doctoral Workshop on Logistics. Our workshop has been a constant in ever-changing times over the past few years and is now celebrating a small anniversary. After two digital online formats, we are now pleased to welcome you again live in Magdeburg. After two pandemic years, we had hoped for complete normality, but the war in Ukraine overshadows our meeting. We all stand for the European spirit of free and peaceful coexistence of all people!

In addition to the pandemic and new developments, our logistics discipline has also changed: While the trend towards digitalization has experienced some acceleration, other trends, such as the global division of labour, are increasingly being challenged. How resilient are global value chains? What are the risks posed by more frequent pandemics or severe climate change? Through our daily research and education, we are trying to find solutions to 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. The pandemic has shown us the importance of an excellent science system.

In our efforts, we would also like to increase the visibility and findability of the contributions through digital open access publication, both for the conference proceedings as a whole and for the individual contributions. As every year we are happy about our international participants and reviewers, 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 16th International Doctoral Students Workshop on Logistics 2023. We hope to see you all here in Magdeburg next year.

Sincerely,

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

Prof. Dr.-Ing. Sebastian Trojahn

# Scientific Papers

# Empirical investigation of the acceptance of the automated shuttle bus in Stolberg

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## Abstract:
Automated shuttle buses are one of the future mobility concepts. As part of the AS-NaSA project, an automated shuttle bus was tested in Stolberg (Germany, Saxony-Anhalt) in 2021. Besides the use, the acceptance of such systems is very important. In addition to the users, however, the residents who live along a pilot route of an automated shuttle bus are also affected. For this reason, a household survey on the acceptance of automated shuttle buses in Stolberg is being conducted in 2022. A questionnaire based on the "Unified Theory of Acceptance and Use of Technology" model was created and every household in Stolberg received two questionnaires. The results show that the current mobility situation and public transport connections in Stolberg needs improvement. Automated shuttle buses are a possibility for the future, but the use of rail has the most support.

## 1. Introduction
Due to demographic change, increasing urbanization, scarcity of resources and climate change, mobility needs to change in the future [1, 2]. One of the future mobility services is the automated shuttle bus, which is electric, connected and safe [3, 4]. Since the vehicles can be shared, they combine the flexibility of individual transport with the cost efficiency of public transport [5]. Therefore, automated shuttle buses are part of the future and sustainable mobility concepts in urban and rural areas (Figure 1) [3]. Right now, the automated shuttle buses are classified in the SAE levels between "Partially Automated" to "Fully Automated" [6, 7]. This development will proceed continuously so that autonomous driving will be possible in the future [8, 9].


*Figure 1: Automated shuttle bus from EasyMile*

However, without the acceptance of the users and the population, technological development will not be able to prevail in the future [10, 11]. One of the reasons for this is that the role of the driver changes completely. With autonomous driving, the driver only has to monitor and no longer steer [12]. There a lot of acceptance studies of automated shuttle buses, but most have focused on user acceptance. For example, in Mainz, where the shuttle bus operated in public space, but without motorized traffic [13]. This survey had a detailed look on performance parameters of the shuttle bus, such as speed, space, and braking. Schäfer & Altinsoy asked passengers about their feeling of safety, future use and driving experience of the shuttle bus operating in Frankfurt am Main [14]. In the pilot operation in Bern, the user experience during the ride, the acceptance of an on-demand operation as well as the preference of the pricing model were investigated [15]. One last example is

a pilot operation in Michigan, where Kolodge et al. asked about safety, performance parameters and reasons why passengers used the automated shuttle bus [16].
In addition to the users, however, the residents who live along a pilot route of an automated shuttle bus are also affected. As road users, they are also confronted with the new technology on a daily basis. Therefore, the acceptance of this population group is of great importance. Currently only three household surveys regarding automated shuttle busses were found. During the pilot operation in Bad Birnbach, residents were asked about the active use and evaluation of the automated bus in Bad Birnbach [17]. Regarding the general evaluation of the vehicles, passengers rated the shuttle buses safer, more reliable and more trustworthy than non-testers [17]. Finally, the question was asked about the willingness to use and openness for autonomous minibus systems in the future [17]. Mantel analysed the acceptance of passengers and residents during the pilot operation in Lauenburg and compared them with each other [18]. A third household survey was conducted in Neuhausen am Rheinfall [19]. The focus of this study was on the ride experience [19]. Since the user survey during the pilot operation in Stolberg was filled out almost exclusively by tourists and hardly by residents, the aim of this publication is to determine the acceptance of the residents of Stolberg [20]. Therefore, as a first step, it is important to understand what acceptance is. This is followed by an analysis how acceptance can be measured. Next, it is important to select the right survey methodology for resident acceptance. Finally, the questions needed for the acceptance survey are selected. In summary, the following research questions are examined (see Table 1).

*Table 1: Overview research question*

| Research Question | Method |
|---|---|
| What is acceptance? | Literature research |
| How can you measure acceptance? | Literature research, best-practice-analysis |
| How can you determine the acceptance of residents? | Literature research, empirical research |
| What questions need to be considered when surveying acceptance? | Literature research, expert interviews, Own research work |

In the following, the methodological approach is first explained and the appropriate method selected. Then the results are presented and discussed. Finally, there is a summary with future research needs.

## 2. Methodical approach

This chapter is divided into place of survey, definition of acceptance measurement, selection of the research method and implementation of the survey.

### 2.1. Place of the survey

Stolberg is with 732 households a small city in the rural area of Saxony-Anhalt (Germany). Nevertheless, a lot of tourists are visiting Stolberg especially at the weekends. As an element of the AS-NaSA project, an automated shuttle bus ran there between 27th June to 30th November 2021. Operating hours were from 10 am and 4 pm between Wednesday and Sunday. The automated shuttle bus EZ10 from EasyMile was used, which is electrically driven and can be used at a speed of 15km/h. The pilot route of 3.2 km lies entirely in public space, where the bus had to interact with a wide variety of road users, such as cars, buses, trucks, cyclists and pedestrians. More than 2,000 people travelled with the automated shuttle bus. During the pilot operation, the acceptance of the passengers was surveyed. In general, the automated shuttle bus was rated very positively and a clear majority was in favour of continuing the pilot operation. However, only 5% of the respondents were residents in Stolberg. The rest were Tourists. [20]

### 2.2. Acceptance measurement

The term acceptance is understood to mean the positive acceptance decision of an innovation by the users [21]. Acceptance research in the field of technical innovations is based on the "Theory of Reasoned Action" by Ajzen and Fishbein and the "Theory of Planned Behaviour" by Ajzen [22]. Two proven models for technology acceptance research are the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) [23–25]. As UTAUT has already been successfully used in previous studies on the acceptance of automated shuttle buses and also in the user acceptance in Stolberg, this model is selected for this questionnaire [20, 26]. The moderating variables and main categories auf UTAUT are:

- Gender,
- Age,
- Experience,
- Voluntariness of Use,
- Expected Performance,
- Effort Expectancy,
- Social Influence and
- Facilitating Conditions [23, 24].

These categories form the basis for the creation of the individual questions.

*Table 2: Selection of the methodological approach*

<table>
<tr><th>Criteria</th><th colspan="6">Type of expression</th></tr>
<tr><td>Scientific approach</td><td colspan="3">Empirical research</td><td colspan="3">Non empirical research</td></tr>
<tr><td>Type of measurement and evaluation</td><td colspan="3">Qualitative</td><td colspan="3">Quantitative</td></tr>
<tr><td>Investigation facility</td><td colspan="3">experimental</td><td colspan="3">Non experimental</td></tr>
<tr><td>Selection procedure</td><td colspan="3">Full survey</td><td colspan="3">Partial survey</td></tr>
<tr><td>Investigation</td><td colspan="3">Longitudinal section</td><td colspan="3">Cross-section</td></tr>
<tr><td>Data collection methods</td><td>Questioning</td><td colspan="2">Content analysis</td><td colspan="2">Observation</td><td>Physiological measurement</td></tr>
<tr><td>Types of survey</td><td>Standardised questionnaire</td><td colspan="2">Unstructured Interview</td><td colspan="2">Guided interview</td><td>Group interview</td></tr>
<tr><td>Medium</td><td colspan="3">Written survey</td><td colspan="3">Online survey</td></tr>
<tr><td>Survey period</td><td colspan="2">1 week</td><td colspan="2">2 weeks</td><td colspan="2">4 weeks</td></tr>
<tr><td>Feedback</td><td colspan="2">In person</td><td colspan="2">Report</td><td colspan="2">Publication</td></tr>
</table>

## 2.3. Selection of the research method

In order to determine the acceptance of the residents near the use of an automated shuttle bus and to answer the research questions, the appropriate methodology must be selected. According to Brosius et al. there are different criteria that have to be considered with the different types of expressions (see Table 2) [27]. As this study is related to a pilot operation of an automated shuttle bus, we are in the field of empirical research, where experiences about reality are collected [27, p. 2]. In order to avoid subjective opinions as much as possible, a quantitative rather than a qualitative measurement is preferred [27, p. 4]. The pilot operation has already been completed, which is why the study cannot be conducted as part of experimental research [27, p. 218]. Since the pilot route led through the entire city, which only has a total of 732 households, a full survey was chosen [27, p. 60]. The study takes place at the time after the pilot operation and thus represents a snapshot, which is why a cross-sectional study is chosen. The questioning methodology is used to collect attitudes or opinions and is therefore best suited to answer the research questions [27, p. 5]. For the types of survey, a standardised questionnaire, a report, an interview as well as a conference are available as choices [27, p. 104-107]. For time and capacity reasons, it is not possible to interview all residents of the city individually, which is why a standardised questionnaire is selected. The questionnaire can be divided into a written questionnaire and an online questionnaire [27, p. 108]. To ensure that all residents have the opportunity to complete the questionnaire and are not dependent on the internet, a written survey was chosen. Four weeks was set as the survey period. The results are published as a report and a publication.
In summary, a household survey of all households will be conducted to determine the acceptance of the residents near the use of an automated shuttle bus. A standardised questionnaire is used as a written survey.

## 2.4. Implementation of the survey in Stolberg

After the study has been designed, the indicators are formed, the data collection carried out and the data analysed [27, p. 28].

### 2.4.1. Creation of the survey

After the methodological approach for surveying acceptance has been selected, the next step is to create the questionnaire by forming indicators and formulating questions (fourth research question). This research question is divided into five sub-questions:

1. Are the traffic situation and public transport services in Stolberg satisfactory?
2. Is the current performance of an automated shuttle bus satisfactory?
3. Should an automated shuttle bus drive through Stolberg in the future?
4. Should automated shuttle buses in general be used as a mobility system in the future?
5. What are the differences in the acceptance of automated shuttle buses between passengers and residents?

On this basis indices are formed in the next step [27, p. 28].
For the sub-question “Are the traffic situation and public transport services in Stolberg satisfactory?” the index “Is the public transport system well developed?“ is being created for example. Subsequently, for each index, various questions are then formulated. The content of the questions is based on the user acceptance survey, a literature review and stakeholder (district, city, tourism promotion, transport company) interests.
Formally, the appropriate question type is selected for each question. Since this is a quantitative evaluation, almost exclusively closed questions are use [27, p. 86]. With regard to the response

options, a dichotomous nominal scale and a six-point Likert scale are predominantly used [27, p. 87]. At this point, a scale without a centre point was deliberately chosen so that the respondents could decide on a tendency [27, p. 90]. Afterwards, the questions are combined into categories in the questionnaire. In total, five chapters are created in the questionnaire (see Table 2). In the chapter on demographic data, introductory questions are asked. The following four chapters are each related to a research question. Chapters 3, 4 and 5 have already been asked in user acceptance, so these three chapters serve to identify the difference between passenger and resident acceptance. How exactly the questions were formulated is illustrated by the example "How often have you ridden the automated shuttle bus in Stolberg?". The response alternatives are "Never", "1x", "2x - 5x" and ">5". This question serves to divide the sample into testers and non-testers. Furthermore, this question is intended to determine how well the automated shuttle bus was used in Stolberg, that is why the quantity is important. After all questions were created, a pre-test was conducted to check the wording of the questions and the answer specifications [27, p. 131]. All questionnaires were printed and sent to all households in Stolberg by post.

#### 2.4.2. Data collection

The questionnaire was sent out on 8th of February 2022. Each of the 732 households received two questionnaires and a stamped envelope so that the questionnaires could be returned free of charge. The residents had until 13th of March 2022 to return the questionnaire. A contact person was always available in case of any uncertainties during the completion of the survey. It took 10 to 15 minutes to answer the questionnaire.

#### 2.4.3. Data analysis

A total of 133 out of a total of 1464 questionnaires were handed in. This corresponds to a share of nine percent. The first step is to digitalize the records [27, p. 30]. Then the data are cleaned and checked for plausibility [27, p. 132]. Only now are the data analysed, mean values and level deviations calculated and the correlations between different variables revealed.

Finally, the quality of the survey is checked. The fact that a full survey was conducted ensures the representativeness of the survey [27, p. 62]. UTAUT was used as an acceptance model and has been successfully applied in previous studies, which ensures the validity of the survey [27, p. 51]. For the reliability check, a test evaluation was conducted to confirm that the method measures what it is supposed to measure. The objectivity of the questionnaire is achieved through the closed questions and the full survey. In addition, the evaluation is done by researchers and the interpretation by trained personnel.

## 3. Results and Discussion

The results are divided into five categories “Demographic Data”, General Mobility in Stolberg”, “Pilot Operation of the Automated Shuttle Bus in Stolberg”, “Future Use of Automated Shuttle Buses in Stolberg” and “General Future of Automated Shuttle Buses”.

### 3.1. Demographic Data

All age categories from 15 to over 80 years are represented in the entire sample. Analogous to the local population in Stolberg, 80 % of the respondents are over 50 years old. With 52% male participants and 48% female participants, the gender distribution of the respondents is equal. 83% of respondents own a car and 80% use their car more than twice a week. In contrast, only 16% use public transport at least once a month. Overall, the sample has a high affinity with cars and 70% are satisfied with their personal mobility. When choosing a means of transport, availability (19.8%), punctuality (17.3%), flexibility (15.9%) and safety (14.4%) are the most important criteria.

*Table 3: Structure of the questionnaire*

| Sub-questions | Chapter in the questionnaire | Number of questions |
|---|---|---|
| | 1. Demographic data | 7 questions |
| Are the traffic situation and public transport services in Stolberg satisfactory? | 2. General Mobility in Stolberg | 8 questions |
| Is the current performance of an automated shuttle bus satisfactory? | 3. Pilot operation of the automated shuttle bus in Stolberg | 4 questions |
| Should an automated shuttle bus drive through Stolberg in the future? | 4. Future use of automated shuttle buses in Stolberg | 7 questions |
| Should automated shuttle buses in general be used as a mobility system in the future? | 5. General future of automated shuttle buses | 2 questions |
| What are the differences in the acceptance of automated shuttle buses between passengers and residents? | Chapter 3, 4 and 5 | Σ = 28 questions |

### 3.2. General Mobility in Stolberg

More than 70% of the respondents are dissatisfied with the public transport connections within and to Stolberg. In order for more people to use public transport in the future, according to the respondents, the frequency of the buses should be increased, the nearest towns should be directly connected and the railway station in Stolberg should be made accessible again.

Although Stolberg is a small town with few inhabitants, it is visited by many tourists, especially at weekends and during holiday periods. 75% of the respondents think that too many cars drive through Stolberg. Due to the fact that it is possible to park on the street in a no-parking zone, there are often traffic jams in Stolberg. Likewise, 75% of the sample believe that too many vehicles are parked in the no-parking zone for longer than permitted. Suggestions for improvement ranged from parking bans, more parking facilities on the outskirts of the city, the use of a shuttle bus to observing the speed limit.

With regard to the first sub-question, it becomes clear that too many cars drive through Stolberg and that the parking ban is often not respected. This leads to traffic jams in the city at weekends and at peak times. Furthermore, the current public transport offer is not satisfactory and should be improved in the future.

### 3.3. Pilot operation of the automated shuttle bus in Stolberg

In this chapter, the respondents were asked about their general attitude towards the project and their experiences during the pilot operation with the automated shuttle bus. While 50% consider the project useful, 50% also consider it not useful. It is striking that the two extreme values ("very useful" = 25.6% and "not useful" = 27.9%) were selected most frequently. This attitude is also evident in the case of riding on the shuttle bus. 30% of respondents have ridden the bus once. The remaining 70% have never ridden the automated shuttle bus.

In the next question, participants rated the satisfaction of riding the automated shuttle bus on a six-point scale from "Very satisfied" to "Very dissatisfied" (Figure 2). More than 50% of the respondents were satisfied with the entire journey and the braking behaviour.

Although this is the majority, both criteria were rated significantly worse than in the user survey. There, for example, 85% of the respondents were satisfied with the entire journey. Speed was also rated better in the user survey than in the household survey. Similarly, however, speed was rated the weakest overall. This was also the case in the user survey. [20]

As a note on these results, more votes were cast on this question than respondents had ridden the bus. Thus, the performance parameters of the bus were also evaluated by people with no driving experience. Nevertheless, it is clear that the technological development of the bus, especially in terms of speed, needs to be improved in the future.

Within the last question in this section, participants had to give their agreement to statements about the automated shuttle bus (six-point scale from "Totally agree" to "Do not agree at all"). Figure 3 shows that 69% agree, that the automated shuttle bus is a tourist magnet in Stolberg. This is only slightly lower than in the user survey (80%). Furthermore, the majority (54%) believe that the bus is a useful addition to the public transport services in Stolberg. However, only 34% agree with the statement that the automated shuttle bus will improve the traffic situation in Stolberg. This value is quite similar to the assessment in the user survey (39%). The

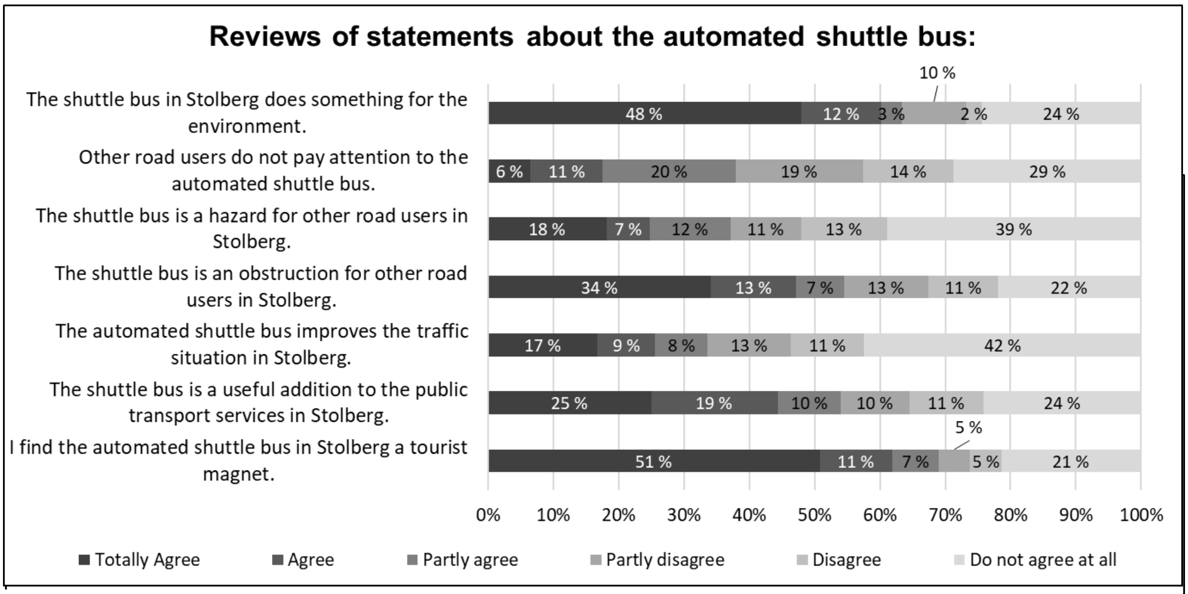


*Figure 3: Reviews of statements about the automated shuttle bus*

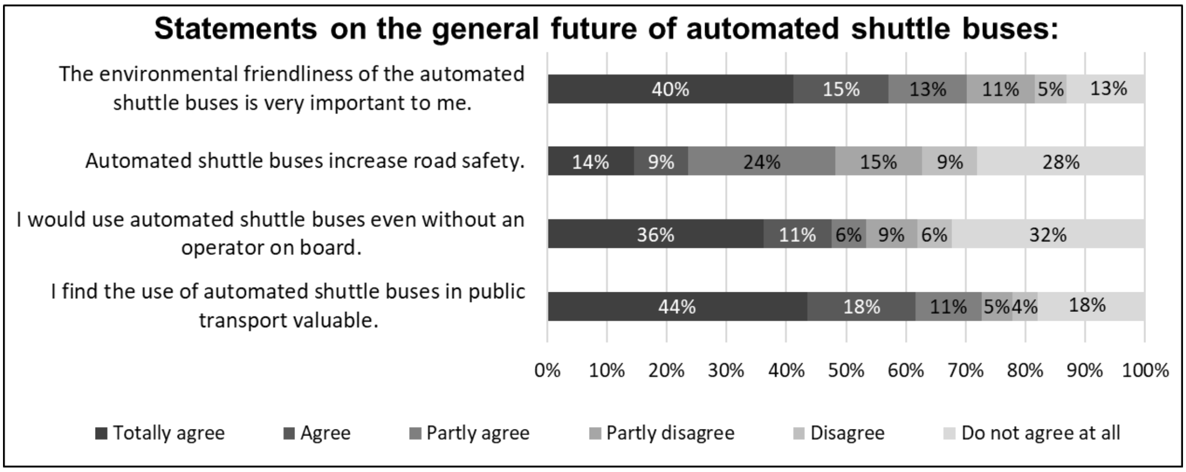


*Figure 4: Statements on the general future of automated shuttle buses*

automated shuttle bus is perceived as an obstruction by 63% of the respondents and as a danger for other road users by 46% of the respondents. On the other hand, other road users seem to pay attention to the automated shuttle bus, as 63% of the respondents stated. Finally, 63% of the respondents voted, that this shuttle bus does something for the environment. [20]
With regard to the fifth sub-question (the difference in acceptance between passengers and residents) it is clear here that the automated shuttle bus and the interaction with other road users were rated worse by the residents. One reason for this question is also that most respondents have not ridden the bus. Regarding the questions about the tourist magnet and the improvement of the traffic situation, the answers are very similar to the results from the user survey. Although the ride of the automated shuttle bus is rated as in need of improvement, the bus is seen as a tourist magnet that can also contribute to environmental friendliness and to improving the traffic situation in Stolberg (second sub-question). [20]

### 3.4. Future use of automated shuttle buses in Stolberg

First, the participants were asked which mobility services should be used in Stolberg in the future. The vote was as follows:

- Diesel-powered minibus: Yes = 69%; No = 31%
- Electrically powered minibus: Yes = 60%; No = 40%
- Rail-based automated vehicle: Yes = 75%; No = 25%
- Automated shuttle bus (current state of development): Yes = 41%; No = 59%

Furthermore, the sample was asked about the requirements that must be met in order for them to also travel with the automated shuttle bus in the future. "Higher speed" (45%), "Different route" (31%) and "Improvement of vehicle technology" (17%) were most frequently mentioned. The improvements to the vehicle correspond to the results from the user survey. However, the adaptation of the infrastructure was also mentioned there, which does not appear in these results. [20]
Nevertheless, 62% of the respondents would be willing to pay money for a ride in an automated shuttle bus in the future. The amounts range from 1.00 to 7.00 euros. The mean value is 1.87 euros. These results are in line with the responses of the user survey, where the mean value was 1.99 euros. This clearly shows that the residents of Stolberg would like to see an expansion of the mobility offer. Analogous to the previous categories, the use of rail is the favoured solution, while the automated shuttle bus scores slightly lower, which is an answer on the third sub-question. However, this also confirms the evaluation of the driving experience (chapter 3.3). [20]

### 3.5. General Future of Automated Shuttle Buses

The participants had to give their agreement to statements about the general future of automated shuttle buses (six-point scale from "Totally agree" to "Do not agree at all"). 68% of the respondents find the environmental friendliness of the shuttle bus as very important (Figure 4). This is the majority, but a lower value than in the user survey (87%). Only 47% believe that the use of these vehicles increases road safety. This is similar to the user acceptance (52%). Overall, 53% of respondents would use the bus even without an operator on board. This is slightly lower than the results of the user survey (66%). This could be due to the fact that only a small part of the sample has ridden the automated shuttle bus. Finally, 73% find the use of automated shuttle buses in public transport valuable. In the user survey, this was 87%, which again confirms this result. This shows that the respondents generally find the automated shuttle buses useful and welcome the future use of such mobility systems (4th sub-question). [20]

## 4. Conclusion

A large number of pilot operations with automated shuttle buses have already been carried out worldwide. Following on from this, the acceptance of the users of these shuttle buses has very often been surveyed. In addition, there have also been some acceptance surveys of residents along the routes of automated shuttle buses. They interact with these vehicles on a daily basis, which is why the acceptance of this group of people is very important. Since in Stolberg mainly tourists have used the automatic shuttle bus and the acceptance of the population is important, a written household survey was chosen as methodology. Besides other household surveys, this study focusses on the permanent continuation of an operation with an automated shuttle bus.

In retrospect, the methodology worked well, as all households could be involved and the time required was not too high. Another possibility would be to use an online questionnaire. This would save costs for sending the letters and the data would be directly available digitally. However, the results show that a large part of the population is over 50 years old and internet access is questionable. Therefore, in order not to exclude anyone from the survey, only a written household survey is suitable.

Overall, the results show that the public transport offer in Stolberg needs improvement. Most residents have their own car and use it regularly. Furthermore, the flow of traffic in the city stagnates at peak times because too many vehicles drive through the city and too many vehicles are parked for longer than permitted in no-parking zones. For this reason, many residents would like to see the public transport services in Stolberg expanded in the future. The use of rail transport is preferred.

The results also show that residents are generally positive about the use of automated shuttle buses and find these vehicles useful. However, the use in Stolberg with the current state of technology is viewed critically. This is reflected, among other things, in the fact that the performance parameters of the shuttle bus were rated somewhat weaker and the use on a different route was often selected.

In conclusion, the results refer to Stolberg and depend on the local conditions and the fact that many residents have not used the shuttle bus. Nevertheless, it can be deduced from these results that in the future use of automated shuttle buses, the residents as well as the users must be involved and a real benefit for these target groups must be apparent. This applies not only to Stolberg but also to other deployment scenarios.

Future research needs should address the acceptance of users and residents in a long-term operation of an automated shuttle bus.

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# Improvement of hotel “Las Cuevas” warehouse logistics

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## Abstract

This research is carried out in the hotel "Las Cuevas", located less than 400 meters from the historic centre of the municipality of Trinidad, Sancti Spíritus, with the objective of applying a procedure that allows the analysis and improvement of the logistics of warehouses in the hotel. For this purpose, information collection and analysis techniques are used, such as: bibliographic review, document review, consultation with specialists, direct observation, interviews, application of a checklist, among others, which make possible the veracity and accuracy of the results of the study. Logistics in general plays an important role in the world and national panorama at present, since it has been established in recent years as a new way of approaching business management, having become a competitive tool within the development strategies of companies. The application of the selected procedure, which includes a general characterization of the hotel, a general characterization of the warehouse under study and a diagnosis of its current situation, concludes with an analysis of the problems detected and improvement proposals to achieve the improvement of logistics in the beverage and liquor warehouse so that it can be certified at the current level or higher.

## 1. Introduction

The COVID-19 pandemic caused an unprecedented level of disruption in the global hotel industry. The combination of local confinements and travel restrictions resulted in the temporary closure of many hotels or operations at a small fraction of their available capacity.

While by mid-2021, some hotels have begun operating, many destinations maintain their borders completely closed to international tourism. Although, during the final months of this year, and mainly, throughout 2022, the development of corporate operations that respond to the unique economic cycle propitiated by COVID-19 is expected, with the objective of overcoming the crisis and reaching stability.

In recent days, Cuba has shown a considerable decrease in the number of confirmed cases of COVID-19, as well as a tendency to control the pandemic. In addition to being guaranteed the coverage of vaccines to immunize the entire population, a controlled and staggered reopening of the national borders is expected, for which the 10 international airports of the national territory are ready to operate and are already preparing their hotels to receive visitors from other countries, all under strict sanitary control measures.

In this scenario, logistics plays an important role since it has been established in recent years as a new way of approaching business management, having become a competitive tool within the development strategies of companies.

Authors such as: [1],[2],[3] state that the supply chain today includes from the design and administration of all the activities necessary for the acquisition of resources and their channelling for transformation to final distribution or delivery. This in turn is interrelated with aspects of quality, customer loyalty, timely presence in the market, sales momentum, operating costs, foreign trade, and the design and redesign of the product or service itself. The appropriate management of information is useful for managers to make effective management decisions and reduce the ecological impact of supply chains, as reaffirmed by [4] and [5].

Business logistics makes it possible to carry out the organization of the company through a set of means and methods that provide a certain order to the processes related to the supply, production and marketing of goods. Among the processes covered by business logistics are distribution, transportation and warehousing. It serves as a link between the production phase and the market phase, which, although they are quite distant in space and time, can be connected thanks to business logistics [6]. The techniques used for this connection focus on the tasks of resource planning and management, whose function is to increase and control efficiency from production to sale to the customer, in order to satisfy the needs of consumers at the lowest possible cost [7].

Currently the world is entering the fourth industrial revolution, which is named by several authors as 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 high-tech strategy project of the German government. It is based on software nomenclature and is used as a synonym for the fourth industrial revolution. The basic concepts of Industry 4.0 ensure the availability of relevant information in real time by networking all elements involved in value creation, the ability to derive optimal value-adding processes from information and data at any time and the realization of an integrated value-adding process information [8].

According to the authors [9], [10], [11] the use of cyber-physical systems (CPS) best describes Industry 4.0. This means the integration of computing, networking and actual physical systems, which provide the basis for new business models and business solutions. In the CS field, the term Logistics 4.0 is used. The above authors define it as the management of the flow of people, and materials between an origin and the point of consumption to meet customer requirements, using the benefits of IT and automation. Relevant Logistics 4.0 technologies are: identification, mobile communication, localization, electronic data interchange, data analysis methods, and data analysis processing [12]. This includes transportation, warehouses and the management of raw materials and finished productions.

The Hotel Cubanacán "Las Cuevas" is a three-star city hotel that accommodates most of the transit tourists visiting the city of Trinidad. It offers laundry services, snack bar and swimming pool, bar, buffet and specialized restaurant, it has the "Discoteca Ayala" in the cave with the same name that distinguishes it from the other facilities of the pole.

One of the main objectives of the facility in recent times has been to obtain the categorization of a four-star hotel. However, some weaknesses are found, primarily in the area of assurance. Its warehouse was categorized in 2019 with the first technical level, which is not satisfactory for its aspirations, as this is the lowest of the categories. As of today, there are also serious supply problems, mainly in the area of beverages and liquors. There are also several points regarding the overcrowding of merchandise, mainly because the warehouse is designed to keep the necessary products only for the hotel; but as it is currently catalogued as a Hotel Complex, it is established as a central warehouse that supplies the five hotels of the complex. All this is presented as the problematic situation of the present investigation.

In view of the above, the scientific problem of the research is: How to contribute to the improvement of logistics in the beverage and liquor warehouse of the hotel "Las Cuevas" so that it can be certified at the current level or at a higher level?

In order to solve the scientific problem, the following hypothesis is proposed as a research hypothesis: If a structured procedure for warehouse logistics is applied, which considers international good practices, current Cuban legislation, national experiences in this field and the particularities of the beverage and liquor warehouse of the hotel "Las Cuevas", it will be possible through its subsequent application the continuous improvement of the same and the achievement of higher levels of certification.

The general objective is defined as: To apply a procedure that allows the analysis and improvement of the warehouse logistics in the hotel "Las Cuevas".

In order to achieve the general objective, the following specific objectives are established:

1. To carry out a thorough bibliographic review, which will provide all the theoretical bases and fundamental applications related to the subject of the research.

2. To apply a procedure that allows the continuous improvement of storage logistics and the achievement of higher levels of certification of the beverage warehouse of "Las Cuevas" hotel.

## 2. Methods or experimental part:

There are several procedures that allow an adequate diagnosis of warehouse logistics for its subsequent improvement. These procedures contain seven work steps. Their operating logic is similar to the Deming Cycle, where the first five stages correspond to "Plan", the sixth stage to "Do", the control step to "Verify" and "Act" overlaps with all the first five work steps or part of them once a complete cycle is completed. From this point of view, it can be stated that the cyclical nature of the procedure allows it to be conceptualized as a continuous improvement tool. The procedure proposed by [13], taking only the first three stages and adapting it to the conditions of the hotel's beverage and liquor store, will be used for this research.

The procedure is shown in Figure 1 and contains four phases, each of them with working steps. From this point of view, it can be asserted that the cyclical character given to the procedure allows conceptualizing it as a continuous improvement tool. The importance of control at each step of the procedure should be emphasized to ensure its correct implementation. The author considers that it should be applied on a quarterly basis, although it should also be done when there are modifications in the products considered or when the facility undergoes any type of change. The following is a brief explanation of the procedure for a better understanding:

### 2.1. General characterization of the entity

This is the first step or work stage and it is important to have a general knowledge of the organization. For this it is necessary to describe a whole set of aspects such as: corporate purpose, mission, vision, services, staff and its completeness, organizational management structure, strategic analysis of the organization.

### 2.2. General characterization of the warehouse

It is important to characterize the target warehouse in order to focus the research on a certain area or locale and to define important aspects such as: warehouse layout, storage technology (classification, storage means, transport equipment, warehouse areas, load flow, functional procedures, storage forms, location and localization of products in the warehouse) and the characterization of the technical state of the equipment.

### 2.3. Diagnosis of the warehouse

This step or work stage is the core of the warehouse diagnosis and covers the study of the physical installation and its management, preferably qualitatively and quantitatively. The aspects to be analysed are: space utilization, warehouse organization, reception and dispatch of goods, planning and control, documentation, conservation and protection and safety standards.

### 2.4. Analysis and proposed solutions

Once the problems have been identified, a set of measures aimed at eliminating or minimizing the problems detected must be proposed. For the implementation of the corrective measures, the conditions of the warehouse must be considered, where possible solutions tend to increase economic results and customer service.

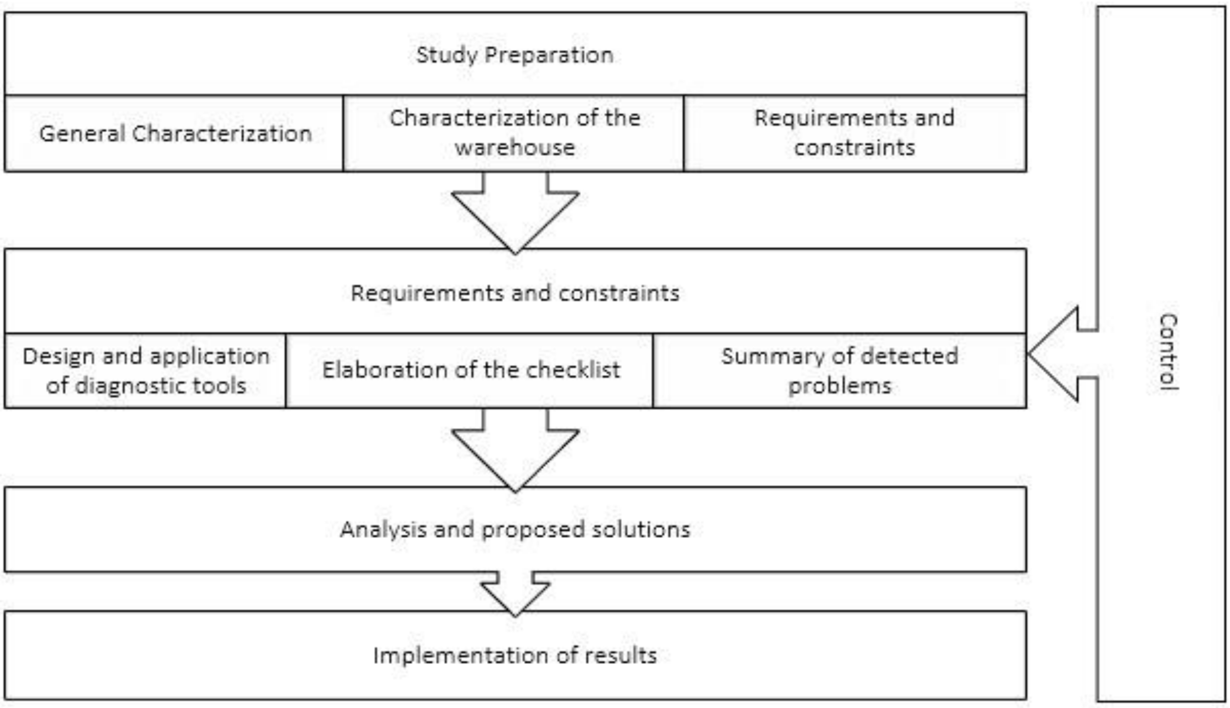


*Figure 1: Methodology*

## 2.5. Implementation of results

At this stage, the implementation of the technological reorganization design of the warehouse is proposed for a trial period of three months. The logistics manager will systematically bring together those responsible for applying each measure and verify compliance with the implementation plan. If any corrective action requires staff training, this manager will coordinate with the training area and the participation of the factory's top management.

## 2.6. Control

The last step of the procedure is a control loop that allows rectifying any deviation detected during the three-month period of operation of the warehouse or of some of the intermediate stages of the procedure. The checklist and indicators proposed in the diagnostic stage are used again to verify whether the problems have been mitigated or eliminated and whether the indicators meet the requirements of resolution 47/2020 Warehouse logistics regulations for entities operating in the national economy. If this does not occur, return to the corresponding work step of the procedure and repeat the rest of the procedure.

# 3. Results and Discussion

The Table 1 shows a summary of the checklist applied and the application of the checklist in the beverage and liquor warehouse, which revealed the following problems in the different aspects evaluated in the warehouse:

*Table 1: Warehouse checklist. First level of categorization. Source: Own elaboration*

| Aspects to be evaluated | Maximum rating to be obtained | Warehouse rating |
|---|---|---|
| Construction condition | 10 | 10 |
| Organization of the warehouse | 30 | 23 |
| Planning and control | 15 | 13 |
| Warehouse documentation | 10 | 7 |
| Standards of conservation and pest control | 10 | 9 |
| Protection, Safety and health of workers | 15 | 13 |
| Product Contamination | 10 | 7 |
| Total | 100 | 82 |

The following deficiencies were found in the different aspects:

## 3.1. *Warehouse* organization

This aspect includes deficiencies such as: the aisles and access doors to the warehouse are not free of products or objects that obstruct or hinder the passage of handling equipment and personnel, due to the problems of overcrowding in the warehouse, so it is sometimes necessary to place goods in the aisles, which also leads to the existence of blocked products in the warehouse. In addition, there is no procedure to reduce handling, nor are the loading schemes for each product defined, and the warehouse does not have a defined area for the repair and maintenance of the unitizing equipment.

## 3.2. Planning and control

Compatibility between stored products is not guaranteed, also due to overcrowding, since due to lack of space, products are sometimes placed in other areas that are not the right ones.

## 3.3. Documentation in the warehouse

There are no procedures for receiving, storage and dispatch. In practice, the personnel in charge know how to proceed, but the procedures are not designed as such.

## 3.4. Storage and pest control standards

Despite complying with the fumigation program established for the warehouse and products, rodents are occasionally present.

## 3.5. Product Contamination

There is currently no cross-contamination in the warehouse and there are strategies to prevent it, but there is no structured procedure in place.
For the analysis of the deficiencies detected in the warehouse, they are grouped into five fundamental problems, considering their similarity:

- Overcrowding *of goods*

The aisles and access doors to the warehouse are not free of products or objects that obstruct or hinder the passage of handling equipment and personnel.
Blocked products are observed in the warehouse.
Compatibility between stored products is not guaranteed.

- Absence of written procedures

There are no procedures to reduce handling.
There are no procedures for reception, storage and dispatch.
There are no procedures to avoid cross contamination.

- Impossibility of a repair area for unitarizing media.

There are no constructive facilities to define an area for the repair of unitarized media.

- Presence of vectors

Despite the existence of a fumigation and pest control program, there are still rodents in the warehouse.

- Absence of loading schemes

There are no loading diagrams for each product. Subsequently, a Pareto diagram is made (see Figure 2), where after weighing all the problems, it is found that the main problem affecting the beverage and liquor warehouse is the overcrowding of merchandise, for which a Cause Effect diagram is made (see Figure 3).

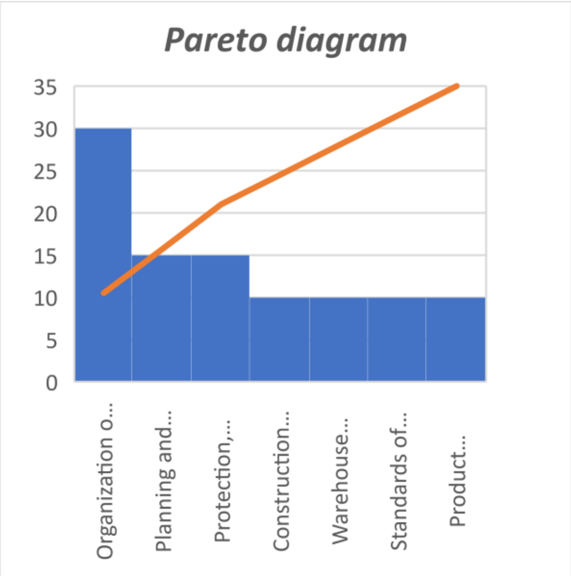


*Figure 2: Pareto Diagram*

Once the fundamental causes of the overcrowding of merchandise in the warehouse have been analysed in the Ishikawa diagram, a series of measures are proposed in order to attenuate or eradicate the overcrowding:

- Search for a place with the appropriate constructive characteristics to establish it as the central warehouse of the hotel complex and that it works only for the insurance of the hotel "Las Cuevas", so that each unit of the complex carries its logistic management independently.
- Organize the warehouse by substituting some direct pallets for shelves to place the merchandise without secondary packaging, whenever possible, in order to optimize the space used.
- Keep a strict control of the rotation of products in the warehouse so that there are no idle or expired products.
- Train workers on the issue of merchandise overcrowding and how to proceed to reduce it.
- The top management, together with the assurance personnel, should establish and record all the procedures that are currently absent, such as: a procedure to reduce handling, procedures for the reception, storage and dispatch of merchandise, as well as establishing the loading schemes for each product.

It is also proposed to analyse and solve the other deficiencies detected in the study in the short term, which does not require significant resources.

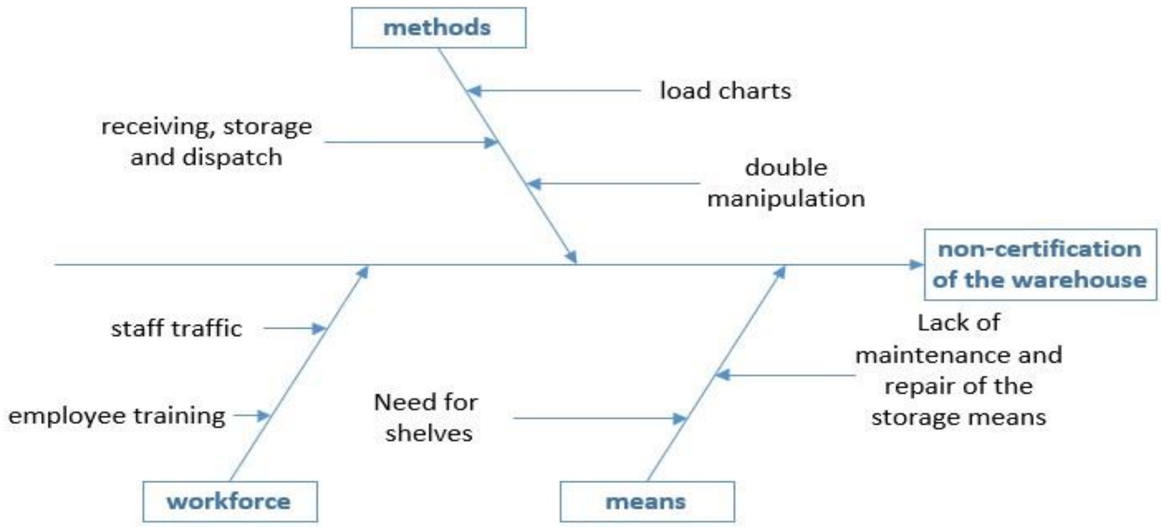


*Figure 3: Cause Effect Diagram*

## 4. Conclusion:

1. The procedure used, contains methods and instructions for the categorization of the warehouse, as well as qualitative and quantitative tools valid for the object of study, varying only small details and consequently improvements are proposed to the deficiencies detected.
2. There are several deficiencies that affect the logistics management of the warehouse, highlighting the absence of written procedures and that the most important problem to be solved with the highest priority is the overcrowding of goods, for which several measures are proposed.
3. Many of the problems identified are soluble in the short term and do not require significant resources. In addition, their detection and subsequent solution is important to maintain the current level of certification and work to achieve certification at a higher level, with the current regulations.

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# System of indicators with a fuzzy-base to evaluate the lean level

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## Abstract

Companies need to systematically and visibly manage the degree of leanness of their processes and evaluate the implementation of new smart manufacturing projects as part of the new industrial revolution. For this, it is necessary to identify indicators that support the decision-making process.This article proposes a measurement system with a tree-like structure of key performance indicators (KPIs) and key result indicators (KGIs). KPIs determine how well the process is performing to achieve results, indicating whether or not it will be feasible to achieve a goal. KGIs define measures to report whether a process met business objectives. Indicators and their supporting measurement elements are identified and classified in a multi-level hierarchy designed to provide answers at the strategic, tactical, and operational levels. In this way is possible to design a hierarchical framework that allow to indicate the casual relationship between different levels of KPI. The tool uses fuzzy logic with two objectives: 1) to allow the treatment of uncertainty and subjectivity associated with the casual relationship between different levels of KPI and supporting elements and the relationship between the indicators 2) for vague and ambiguous data as input parameters to the model from different domains and scales.

## 1. Introduction

Lean manufacturing (LM) is an integrated socio–technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer and internal variability. LM encompasses individual management practices that can work synergistically to create an optimized system.

However, companies that have been applying lean tools and methodologies show shortcomings in the evaluation of their improved performance. The causes cited for this gap are largely due to a lack of understanding of the concept of lean performance and appropriate models to monitor, evaluate and compare the evolution of "lean level". In a lean implementation process it is necessary to use indicators to monitor progress and support the decision-making process. A structured framework of performance indicators is crucial in measuring the distance between the current and the desired operations, identifying the track progress towards closing the productivity gaps [1, 3].

Currently most organizations use qualitative evaluation methods based on questionnaires or a group of metrics used simultaneously to determine the level of application/implementation of the methodologies and lean tools. The challenge of using performance indicators and metrics concerned with the assessment of the lean level of an organization, it is the ability to define a set of indicators including all dimensions of the lean approach. Furthermore, the synthesis of a set of indicators in a single lean metric is also in itself a challenge due to the different measurement units.

Fuzzy logic modelling offers a simplistic yet comprehensive approach to lean performance evaluation, while allowing the use of qualitative and quantitative indicators simultaneously.

In this context, this paper presents a model based on fuzzy logic that aims to determine the lean level of an organization, which could be seen as a modelling and decision-making tool for complex systems. The tool uses fuzzy logic allow the treatment of uncertainty and subjectivity associated with the casual relationship between different levels of KPI and supporting elements and the relationship between the indicators.

The paper is structured as follows: on section 2 is discussed the need to measure the lean level of an organization, main perspectives to assessing the level of leanness that has been suggested in literature, and main advantages that can be generated by the use of fuzzy logic in the evaluation of the lean level. Section 3 presents a detailed description of the lean assessment approach proposed.

## 2. Research background and Fuzzy Logic

Nowadays, when the subject of productivity and business success is addressed, there are several relevant issues that are the subject of research, for example: Why are not all organizations successful? Why the success formulas do not apply equally in all situations? What does it mean to be lean? How lean are the processes of our organization? How can my organization quantify the fats identified? And what is the most appropriate lean evaluation model in order to monitor strategies for increasing productivity and continuous improvement? [2,13].

We can find in the literature several definitions for the term lean level of an organization. For example, the lean level as the performance level of the stream value compared to perfection, a measure of the implementation of lean practices, or absence of fat that it means less use of the inputs to fulfil the objectives of the organization and an improvement in the outputs. Thus, one of the major challenges facing this area, it is related with the development of models to assess and validate the effectiveness and efficiency of lean thinking implementation in organizations [11].

According to some authors, lean assessment methods can be categorized into four groups: Value Stream Mapping (VSM), Qualitative Assessment Tools, Performance Indicators and Benchmarking [4]. Although there are several different methods of measuring the various perspectives of lean production, in literature there is no holistic assessment approach to determine the level of implementation of lean thinking in organizations [11].

### 2.1. Research Background

The reference [5] proposes the performance pyramid (see figure. 1) with the purpose to link the hierarchical view of business performance measurement with the business process review. On the top of the pyramid there is a corporate vision that depends on market and financial goals (e.g. market share, return on investment, etc.). At an intermediate level, objectives deal with achieving and maintaining high productivity and quality, with fast response, sufficient flexibility, and short lead times. At the bottom level there are the operations mainly characterized by non-financial indicators (e.g. cycle time, material losses, mean time to failure, etc.). The pyramid points to a range of target related to both external effectiveness and internal efficiency [1].

These objectives can be achieved through measures at various levels in the hierarchy as shown in the pyramid at the right side of figure 1. The measures interact with each other both horizontally at each level, and vertically across the levels in the pyramid. [12]. Obviously, the pyramid is a tool that requires to be adapted to different industrial contexts, and it represents a very interesting approach for implementing a Performance Measurement Systems (PMS) in a competitive company. The design of the whole framework, the identification of the proper Key Performance Indicators (KPIs) and the implementation of the monitoring system, represents currently the real challenge for most manufacturing plants.

The PMSs are considered essential in manufacturing processes, since they allow monitoring and controlling the factory facilities in order to enhancing the productivity and improving the manufacturing system performance. A PMS consists of a set of metrics that are able to quantify the efficiency and effectiveness of manufacturing operations according to a top-down perspective, that depends from both internal and external factors. In manufacturing systems, once a KPI set is defined in a PMS, every parameter reflects one facet of the system performance [1].

According to ISO 22400, KPIs are defined as quantifiable and strategic measurements that reflect the critical success factors of an organization. Key performance indicators are very important for understanding and improving production efficiency. The values achieved by the KPIs are very helpful in the decision-making process, enabling the identification of problems and the undertaking of corrective or improvement actions. Proper use of information from the KPI measurement should contribute to more effective management of the organization's resources [9].

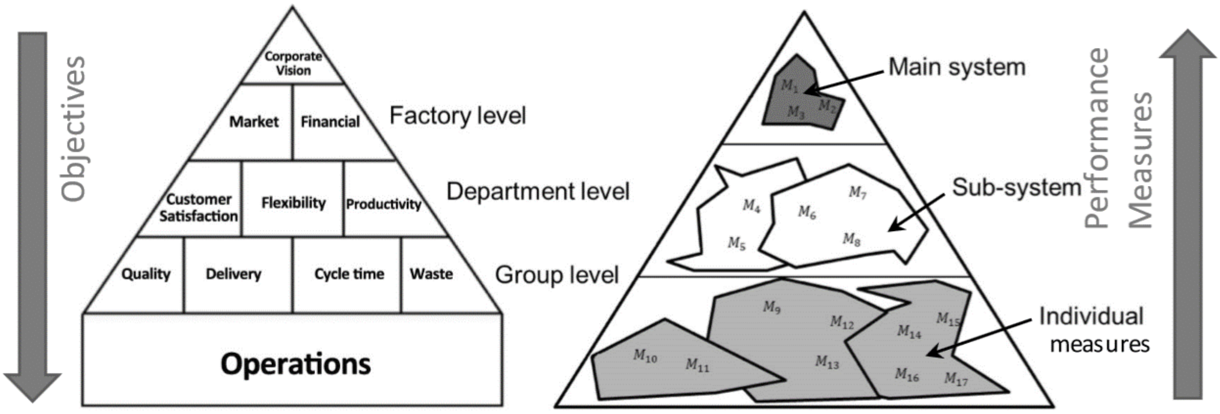


*Figure 1: The performance pyramids [1]*

## 2.2. Fuzzy Logic

From the point of view of socioeconomic phenomena, it is necessary to have models that more accurately capture reality, since it involves imprecision, lack of definition, lack of borders, subjectivity, undefined classifications, etc., that is concepts and variables are manipulated that do not fit with classical logic and, however, for their analysis it is necessary to use mathematics.

Precisely, in the search for models that take these realities into account, fuzzy logic emerges as a mathematical model that allows the use of concepts related to reality following behavior patterns similar to human thought [7].

A fuzzy logic system converts input variables (quantitative and qualitative) into linguistic variables through membership functions or fuzzy sets, which are evaluated using a set of if-then fuzzy rules. Then the system outputs are converted into crisp values (crisp) through a process of concretion (defuzzification), which allow providing information for decision making. A fuzzy logic system uses any type of information and processes it in a similar way to human thought; For this reason, fuzzy logic systems are suitable for dealing with qualitative, inaccurate and uncertain information, which also allow dealing with complex processes, which makes it an interesting alternative for modeling decision-making problems [7].

Fuzzy logic is related to and based on the theory of fuzzy sets, according to which the degree of membership of an element in a set is determined by a membership function that can take all the real values included in the interval (0, 1). In this way, while in the rigid framework of formal logic the utility of a company, for example, is low and gives it a value of zero, or is high and gives it a value of one, for fuzzy logic it is possible also all the intermediate conditions of utility such as “very low”, “slightly low”, “medium”, “relatively high”, etc.

The essential steps for the design of a fuzzy system are [6]:

Identification of the type of problem and the type of fuzzy system that best fits the data.

1. Definition of input and output variables, their fuzzy values and their membership functions (fuzzification or parameterization of input and output variables).
2. Definition of the knowledge base or fuzzy rules.
3. Obtaining system outputs through the information of the input variables using the fuzzy inference system, which uses composition operators.
4. Transfer of the fuzzy output of the system to a clear or specific value by means of a defuzzification system.
5. Adjustment of the system validating the results.

# 3. Results and Discussion

The methodology to implement a fuzzy aggregation method is compound by nine steps; each one is described as follows:

1. Choose an indicator’s set for each perspective: the reference [8] perform a comprehensive review of the literature, presenting an overview of current Lean assessment tools, methods, and techniques available in the literature, demonstrating the dimensions used in each. This analysis is taken as a basis to propose an evaluation tool in this section.
2. Build a global indicator based on the statistical analysis: the main goal in this step is to know how we can group the indicators ensures the maximum correlation among the items in the component and minimum correlation among the components.
3. Indicator fuzzification: Every time we want to build new indicators based on aggregation methods is important to normalize the indicators. A sigmoidal membership function is proposed as an aggregation method. The parameters of these functions are determined by setting two values. The first is the value at which it is considered that the statement in the predicate is true (gamma). The second is the value for which the data makes almost unacceptable the corresponding statement (beta) [10]. The sigmoidal membership function is calculated as follows:

$$S\ (x, \alpha, \gamma)_k = \frac{1}{1+e^{-\alpha(X_k-\gamma)}} \quad (1)$$

$$\alpha = \frac{\ln(0.9)-\ln(0.1)}{\gamma-\beta} \quad (2)$$

Where:
S: Value of truth of the criterion of measurement of indicator "k"
Alfa (α): Sigmoidal function parameter
X: Calculated value of the indicator "k" according to the company
Gamma (γ): Value acceptable. It would be equal to the value at which the indicator is considered acceptable.
Beta (β): Value almost unacceptable: It would be equal to the preimage of a symmetric sigmoidal function for the optimal value defined for the indicator.

The evaluation of the qualitative indicators is carried out through a table work of the group of experts. These will give a truth value between 0 and 1 where the values closer to 1 are considered as higher truth values that indicate the degree of compliance with the approach of the descriptor in the area. To do this, we will work with the scale shown in Table 1. Given that this scale covers the widest spectrum of verbal predicates possible in the analysis of the experts (very high, high, medium, low, very low and terrible), it also considers that truth values less than 0.5 indicate the falsity of the predicate, so the analysed descriptor is assumed to be lousy in compliance with the premises of fuzzy logic [10].

*Table 1: Scale to determine the behaviour of qualitative indicators*

| Ratio | Range |
|---|---|
| Very high | 1-0.9 |
| High | 0.9-0.8 |
| Medium | 0.8-0.7 |
| Low | 0.7-0.6 |
| Very low | 0.6-0.5 |
| Critical | 0-0.5 |

4. Estimation of the weighting coefficients: the weighting coefficients represent the relationships of relative importance in the multi-criteria aggregation process. For the evaluation of these coefficients, the Analytical Network Process (ANP) is used [14]. The ANP allows to generate a network, considering all the existing relationships between the levels (perspectives) and between the alternatives (indicators) without having to assume axioms of independence. This uses a super matrix approach to calculate the weighting factors and check the consistency of the exercise through the vectors and eigenvalues. As a result, a set of weighting factors is obtained (by perspective, by descriptor and equivalent) that are less sensitive to judgment errors and whose consistency can be determined quantitatively. The scale to define the weights will be a continuous number between [0, 1].
5. Aggregation fuzzy methods: a global indicator is build considering the weight for each simple indicator and its value of truth. Under the principles stated above and using compensatory fuzzy logic to compensate the global indicator, would be defined as follows:

$$GI = \forall_{j=1}^{j=n} \left[W_j \rightarrow V_j\right] \in [0,1] \quad (3)$$

Where:
Gi: Value of truth of the global indicator “i”
$W_j$: Weight of the “j” simple indicator
$V_j$: Value of truth of the simple indicator “j”.

The result set from the expression 3 will be a continuo’s number among [0, 1] where one is the optimal result and zero the worst result [10].

While quantitative assessment tends to result in an acceptable performance level, qualitative assessment reflecting stakeholders’ perceptions or the context of the firm may create different assessment perspectives. Therefore, the lean index was built using both quantitative and qualitative measures, to give an overall view of the organization’s leanness efforts. The measures utilize a ratio-based approach, using fuzzy logic, integrating five main performance dimensions (Quality, Customer, Process, Human resources, Cost). The section integrates a perceptional approach with 61 quantitative and qualitative items.

**Quality**

Q1. Defect rate
Q2. Rework rate
Q3. Scrap rate
Q4. Failure rate at final inspection (First time through)
Q5. Inspection carried out by autonomous defect control (poka-yoke devices)
Q6. Employees identify defective parts and stop the line.
Q7. Processes are controlled through measuring inside the process.
Q8. Process-focused management is employed in throughout the firm.

**Customer**

C1. Customer satisfaction index
C2. Market share (market share by product group)
C3. The customer complaint rate
C4. Customer retention rate
C5. Total number of products returned by the customer/total sales
C6. Our customers are directly involved in current and future product offerings.
C7. We have frequent follow-up with our customers for quality/service feedback

**Process**

Production Process

P. PP 1. Overall Equipment Effectiveness (OEE)

P. PP 2. Size of the adjustment and repair area/total area

P. PP 3. Capacity utilization rate (idle capacity/total capacity)

P. PP 4. Space productivity

P. PP 5. Kanban, squares, or containers of signals are used for production control.

P. PP 6. Equipment is grouped to produce a continuous flow of products

P. PP 7. SPC techniques to reduce process variance.

P. PP 8. TPM is applied throughout the firm.

P. PP 9. Value stream mapping is employed in throughout the firm.

P. PP 10. Non-manufacturing operations are standardized.

Time Effectiveness

P. TE 1. Cycle time

P. TE 2. Takt time

P. TE 3. Total down time/total machine time

P. TE 4. Total time spent on unplanned or emergency repairs/total maintenance time

Inventory

P. I 1. Stock turnover rate

P. I 2. Total inventory/total sales

P. I 3. Raw material inventory/total inventory

P. I 4. Total work in progress/total sales

Delivery

P. D 1. Number of times that parts are transported/total sales

P. D 2. Average total of days from orders received to delivery

P. D 3. Order processing time/total orders

P. D 4. Total of orders delivered late per year/total of deliveries per year

P. D 5. Production is pulled by the shipment of finished goods.

P. D 6. Production at the stations is pulled by the current demand of the next station.

P. D 7. To establish long-term relationship with our suppliers.

P. D 8. To include our key suppliers in our planning and goal-setting activities.

P. D 9. Suppliers are directly involved in the new product development process.

P. D 10. Key suppliers deliver to plant on JIT basis.

P. D 11. We and our trading partners exchange information that helps establishment of business planning.

**Human Resources**

HR1. Labour turnover rate

HR2. Total indirect employees/total direct employees

HR3. Total of employees involved in lean practices/total employees

HR4. Total of problem-solving teams/total employees

HR5. Sales per employee

HR6. Employee drive suggestion programs.

HR7. Continuous improvement and compensation link is evident.

HR8. Operators and supervisors are cross functionally trained and flexible to rotate into different jobs.

HR9. Leaders are responsible for how the value-added work gets done

**Cost**

Co1. Annual transportation costs/total sales

Co2. Inventory costs/total sales

Co3. Total warranty costs/total sales

Co4. Total cost of poor quality/total costs

Co5. Total cost/total sales

Co6. Average cost per unit

Co7. Total prevention costs/total costs

Co8. Total prevention costs/total sales

The lean index is modelled in Fuzzy Tree Studio Software. Figure 2 shows the five defined perspectives and as an example in figure 3 it is indicated how the simple predicates are established for each of the perspectives. These predicates correspond to fuzzy variables that have been normalized (quantitative) or linguistic labels (qualitative).

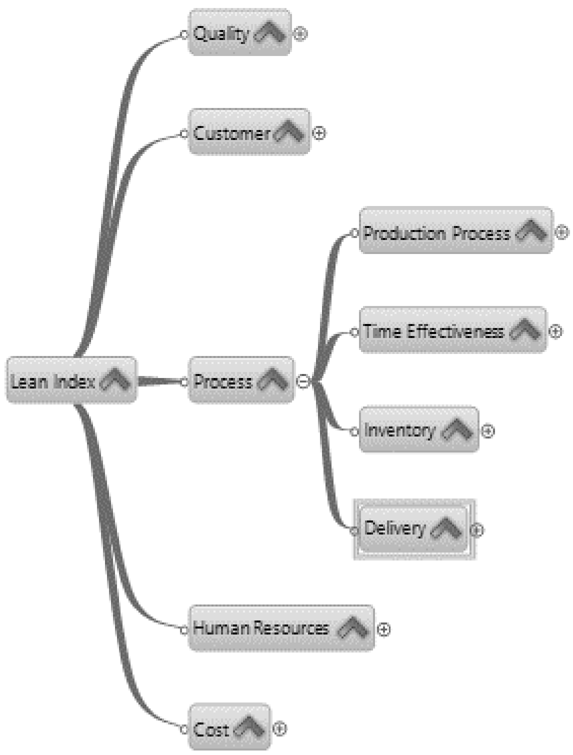


*Figure 2: Fuzzy tree to calculate the lean index*

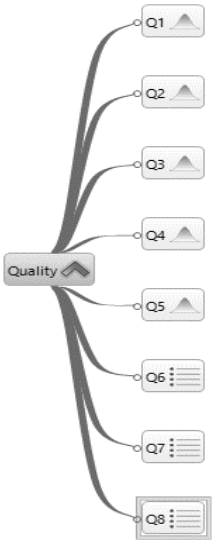


*Figure 3: Fuzzy tree to calculate a perspective*

Once designed the fuzzy tree in the system must be associate the data set. To analyze the lean index must be analyzed individually the behavior of each predicates and the overral indicator . The scale was defined, considering the same values of truth of Table 1.

## 4. Conclusion

Multiple assessment tools have been designed to measure different and often individual aspects of lean implementation. While some existing studies measure leanness level through perceptual evaluations, other studies utilize a quantitative assessment approach. Using only one qualitative or quantitative approach in lean assessment efforts may create a bias both in practice and theory. While quantitative assessment leads the organizations to an acceptable leanness level, stakeholders' perceptions about leanness level may result in an opposite result. To decrease this possibility, organizations should utilize both perceptional and measurement approaches simultaneously to assess their lean implementation efforts. Therefore, this index employs an evaluation approach that includes both quantitative and qualitative bases, constructed on fuzzy logic.

The lean level indicator provides a diagnosis that allows to adequately guide the improvement approach to be followed in a company. The evaluation considers five fundamental components: quality, client, process, human resource, cost integrating 61 items (quantitative and qualitative). This indicator was developed under the principles of compensatory fuzzy logic, based on the advantages of using fuzzy predicates and their representation through fuzzy trees. The use of Fuzzy Tree Studio allows the evaluation to be relatively easy to carry out, thus being a feasible tool to apply.

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# Analysis of flexibility on the FTS

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## Abstract
Mobility is an important societal issue, and one that COVID-19 has touched on to a large extent. The epidemic situation is slowly recovering, but the use of flexible transport systems is not widespread. I will present the need to examine the approach to DRT and the competitive deployment of flexible transport systems from the perspective of mobility as a service. For the effective design and deployment of flexible transport systems, it is necessary to collect the parameters that can be qualified and to establish the methods to analyse their effectiveness. The parameters to be analysed need to be established for each FTS categorical operational concept. Appropriate flexibility indicators for flexible transport network variants. The context in which the indicator can adequately qualify flexible transport systems is debated. The outcome of this research is to establish resilience parameters (for A-FTS) and describe operational concepts (for A-B-C-FTSs) based on preliminary research.

## 1. Introduction
Mobility is an essential part of our lives, which is reflected in the use of private and public transport. Walking can be considered as a private mode of transport, but it is extremely limited in terms of spatial and temporal mobility. Furthermore, walking and cycling can be influenced by hectic factors such as the weather, which can influence the decision of the passenger to use mobility devices [1]. The car is the most accurate personal transport vehicle to meet travel needs, but it has several negative impacts on travel culture and it is expensive and has a high specific environmental impact [2]. Classic public passenger transport modes, such as buses and trains, offer a satisfactory service in terms of time coverage at a generally low fare, but are very limited in terms of spatial coverage.
Nowadays, it is fashionable to look at personal mobility equipment in terms of whether it is owned or hired by the passenger. This is the approach of MaaS (Mobility as a Service) [3], which is the provision of a mobility service by autonomous vehicles, including the use of personal transport available to members of the community, which is in effect a rental system. A sustainability approach can be seen between the two theories, shifting in the direction of minimising private ownership. All the while, the car's using/parking ratio of off-road transport should be higher.
Demand Responsive Transportation (DRT) and Flexible Transportation Systems (FTS) are the same concept in several research studies. Flexible transport systems include all passenger transport services available to the community that differ in their spatial and temporal demands from a service with a fixed stop and a fixed route [4]. In this context, demand responsive transport systems are a subset of flexible transport systems. A more detailed overview is therefore recommended and will be analysed in more detail in the following chapters.

## 2. Modes of mobility
There are micro- and macro-level mobilities. The major variants of these have been mostly described in the previous chapters. It is worth examining the spatial/temporal flexibility of each mode of travel as a function of capital requirements. The Figure 1 illustrates this. The cost of transport modes is very different for each type of travel options. The usage of private cars is a high-cost form of travel to meet mobility needs but can perform mobility needs at a high level. However, it is limited due to several factors: (i) congested roads [5], (ii) limited parking spaces [6], (iii) poor air quality [7], (iv) noise pollution [8]. Environment-friendly mobility modes, such as walking and cycling, require minimal investment and have a positive impact on health, but depend on spatial, temporal and weather parameters.

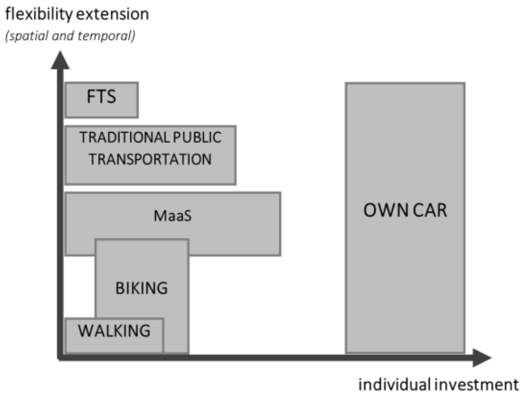



*Figure 1: Flexibility opportunities (spatial and temporal) as a function of individual investment*

Mobility as a service has made available the possibility for individual users to use private transport that is not economically viable and/or not available to them. Examples of such services are carsharing, carpooling, bike-sharing, etc. The investment cost is not borne by the user, so use is possible at a rental fee, but no other cost is involved. The mobility in space and time for these solutions can be local, interurban or even long-distance. The deployment of such systems has spread and is operating competitively in places with high average population densities. The disadvantage of MaaS systems is therefore their accessibility in countryside.
Flexible transportation systems can be organised and designed to manage individual and collective travel needs. Flexible transport systems can thus meet a wide range of mobility needs at low investment costs. In the remainder of the paper, flexible transport systems will be examined as a result of the literature review of FTS and DRT systems, and thus their characterisation will be examined in the subsequent chapters.

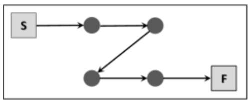
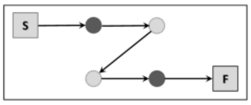
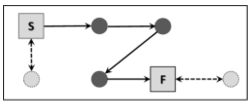
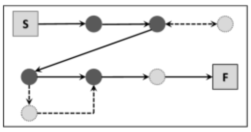
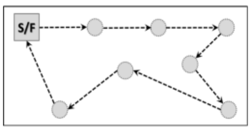
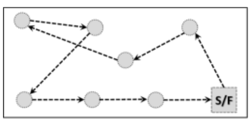
## 3. Flexible Transportation Systems

Several schematic network figures have summarized in the previous literature research on demand-responsive (DRT) and flexible transport systems (FTS). Detailed source and literature research can be found in [9]. The result of that research is 6 DRT and FTS design samples and several flexible elements have been identified according to the transport network design.
The 6 DRT and FTS design samples can see in Table 1. (I-II-III-IV-V-VI. types) where a transition between the 0-1 elasticity measure can be observed. The Roman numerals also correspond to the numerals in the first column of Table 1., where further analysis requires further narrowing down the network elements for new grouping purposes (last column). For the theoretical and practical studies, the 6 schematic network diagrams had to be further narrowed down by applying a method and approach. In the following chapters, the flexible categories A-B-C are presented in detail. Furthermore, the flexible parameters relevant for public transportation planning are identified.

Some major research questions (FTS):

- Which areas can each type of FTS be used?
- What operational parameters can be used to qualify a given type of FTS service?
- What is the possible size of the service area for different types of FTS?
- When is an FTS journey optimal?
- When is an FTS journey optimal?
- etc.

*Table 1: Literature and new network categories*

| Network from previous literature review [9]: Name (network with …) | | | New FTS category |
|---|---|---|---|
| I. |  | fixed route and stops | A-FTS |
| II. |  | fixed route with some optional stop(s) | |
| III. |  | route extension from start or ending stop(s) | B-FTS |
| IV. |  | extension with back-and-fort and by-pass | |
| V. |  | fixed start/ending points and route/tour is flexible | C-FTS |
| VI. |  | fully demand responsive route | |

## 3.1. A-FTS category

The A category flexible transport system the A-FTS, is not very different from classical public transportation modes, as its network elements include a fixed route and fixed and/or optional stops. This category can be extended to public transport by rail in addition to passenger transport by bus and coach. The logic is that the vehicle stops at the stops indicated in the schedule only if there is a need to alight and/or board. With this option, a fixed route service can be provided to meet actual travel demand.

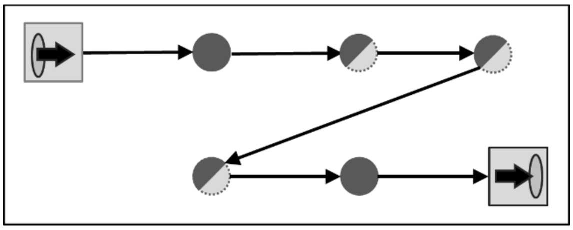


*Figure 2: Network of A-FTS*

In terms of flexibility, it provides minimal and only time flexibility to the transport system. Currently, the bus just stops at bus stop where if there any demand but is rarely used in rail transport. However, it is wasteful of energy and time for a vehicle to stop at a stop or station where there are no passengers alighting and/or boarding. In this case, it is not only time that can be saved in the case of a journey, as energy can also be saved by skipping unnecessary deceleration and acceleration phases. Moreover, in a similar application, a reduction in brake wear between two services can be demonstrated. At the same time, this flexibility has positive implications for operations. For passengers travelling between origin and destination, a long-distance train can arrive at their destination more than 10 minutes earlier by continuing without stopping at each stop.

Even for the use of A-FTS, it is essential to use a digitalisation system to register take-on and take-off requests and to predict the expected arrival/departure time window depending on the existing demand. The system would provide a time window moving within a pre-defined framework as information. The maximum travel time between the two endpoints would be the travel time calculated by stopping at the take-on and take-off points. The minimum travel time is the travel time between the two endpoints without stopping.

$$T_{min} \leq T_{real} \leq T_{max} \quad (1)$$

Equation 1 means the time window for the whole journey, but this time window may change at the time of departure of the journey and during real-time data processing. The travel time should not fall outside the maximum and minimum journey times only in case of an accident or an emergency.

In the case of bus transportation in Hungary, it is well known that this system works on the logic that the vehicle stops only when needed. However, due to the time overrun caused by missed stops, the departure time indicated in the timetable at later stops can lead to misleading and unsuccessful journeys. A continuous information system is therefore an essential part of an efficient service.

It can be seen that this category only provides time flexibility by using existing interconnected infrastructures. It may have a viable application in macro-regional road and rail passenger transport, such as trams or suburban railways, as well as in regional and long-distance transport.

## 3.2. B-FTS category

The B category flexible transport system the B-FTS, is a vision that can complement the classic public bus transport network with flexible elements for example extension with back-and-fort and by-pass, D2D etc.

The B-FTS contains significantly different types of flexible network elements compared to the previous category, which can affect the flexibility of the system. This network has a fixed backbone on the route, which is almost always traversed by the transport vehicle. The conditional mode of the previous sentence will be explained in the next paragraph (iii). The stops on the backbone can be fixed or optional. In addition, there are optional stops which are not located on the backbone. They will only be served by the transport vehicle if the need exists. Where stops outside the backbone are accessed, they may be approached by a predefined route, which is an optional route.

The different optional routes can be: (i) a detour from the starting or endpoint, which is considered as a shortcut route without special claim; (ii) branches off the ridge, which branch off at the same point on the backbone and return at the same point; (iii) a by-pass where the departure and return from the backbone point do not coincide; (iv) door-to-door passenger services from the backbone by means of a detour, which are not a predefined service function but are in any case optional.

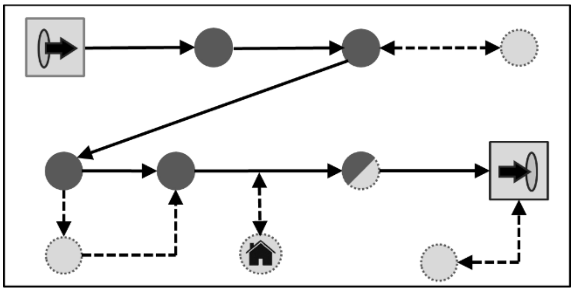


*Figure 3: Network of B-FTS*

The flexible transport category B-FTS cannot be used for fixed-route passenger transport. However, it is widely useable in public bus transportation. A flexible element can be served by high-capacity buses and minibus if the infrastructure for passengers to and from the bus and minibus is adapted to the conditions of classical bus transportation. However, smaller capacity vehicles can also be used, as it is not necessary to have a higher capacity in off-peak periods, which is a fraction of the nominal traffic. A smaller vehicle can efficiently carry out the door-to-door service during off-peak periods, unlike a large capacity vehicle.

Depending on the previous ideas, the B-FTS category can be divided into three transport management tasks. The first is where stops are defined to serve an area and are served by a route schedule that includes optional routes, other than fixed ones, according to various parameters. If there is no demand for travel at the points covered by the optional routes, passenger transport is shorter in terms of route and faster in terms of journey time for the whole journey. The scope may also include interurban services, for example in small rural areas or on suburban bus routes. The concept as described can operate throughout the day. The second case is when door-to-door passenger transport needs can be met on a transport network with fixed and optional elements. This level offers greater potential for category B-FTS, which can meet maximum travel mobility needs. Again, of course, a travel demand processing/information system is essential for efficient operation. D2D travel needs cannot be fully served by such a flexible public transport system. In most cases, these needs can be served more efficiently in the early morning or evening hours, as extra by-pass trips would lead to a large increase in travel time and distance. It is known that the less demand a mode must satisfy, the more flexible it can operate, and therefore the better the D2D demand can be met during off-peak periods. Individual needs, such as door-to-door passenger transport, may be available to passengers at an extra cost. This is possible on urban and suburban lines, mostly during off-peak periods.

### 3.3. C-FTS category

The C category flexible transport system the C-FTS, in which the route is adapted to the full travel demand. Individual needs determine the pick-up or drop-off points involved in a route.

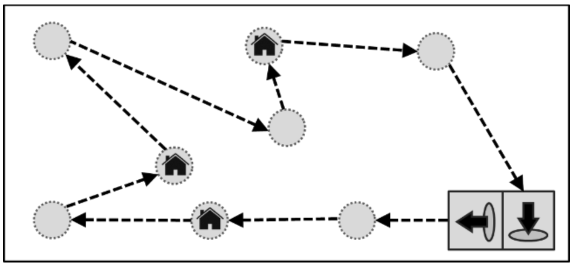


*Figure 4: Network of C-FTS*

The classic case is where the system origin and destination are at the same location, through which it provides a distribution and/or collection to serve, for example, an intermodal hub. However, this category does not only correspond to a flexible roundtrip. Self-organising service structures can be included in this category. Taxi, airport transfer belongs to this level of system when the travel demand draws the route as in a pulling system. The case of a taxi, which is completely unbounded from a network point of view, so that it can satisfy D2D demands efficiently, since the system does not contain fixed network elements. This option operates at a relatively expensive fare, so it should also aim to design for the C-FTS category based on public transport criteria.

Providing optimal operating conditions and keeping fares at an economical level can make this level of service available to everyone.

In the introduction, the relationship between the concepts of FTS and DRT was explained. For this category, it is shown that a demand responsive transportation systems structure is also available for self-organised services and round trips. A 100% transport flexibility for individual mobility needs cannot really be achieved by public transport. Conditions for planning and optimisation need to be set up and considered.

## 4. Flexibility definition and parameters

As a result of the characterisation of the basic FTS categories, it can be concluded that these A-FTS, B-FTS and C-FTS categories are associated with several mobility problems. From various macro-regional transport systems to passenger transport services serving local mobility needs, applicable proposals are included in the category descriptions presented in Chapter 3.

About flexible transport systems, there are several different parameters to be considered between design and practical implementation.

### 4.1. A-FTS Flexibility parameters

In order to quantify the flexibility that can be defined in A-FTS, it is necessary to collect the parameters that influence the service flexibility of each category.

One of the measurable parameters of service flexibility is the rate of the number of fixed stops ($n_f$) and the number of optional stops ($n_o$).

$$e_{fo} = \frac{n_f}{n_o} \qquad (2)$$

Equation 2 is a ratio that can provide a basis for comparison of two A-FTS options. However, this ratio is not sufficient for a set of rating indicators, but additional specific parameters and ratios are needed to compare operational characteristics.

Such an indicator could be the difference of maximum and minimum destination and arrival times. This difference is a $T_{win}^{stop}$. This parameter cannot be longer than the maximum waiting time window ($T_{max}^{wait}; T_{win}^{max}$).

$$T_{win}^{stop} = t_{arrive}^{max} - t_{dep}^{min} \leq T_{max}^{wait} = T_{win}^{max} \qquad (3)$$

In the case where several regional nodes have fixed departure times in their time windows, the route has to be fragmented several travel sections for the purpose of calculating flexibility. The parameters described above are then examined for each section and a comparable value is obtained by averaging the results.

The indicators calculated from the number of passengers carried are not relevant for the A-FTS category, as they can be used in transport areas (rail, bus) where the number of passengers is high.

However, the rate of passengers alighting ($N_{alig}^{pass}$) and/or boarding ($N_{board}^{pass}$) can be used to classify fixed and optional types of stops.

$$e_{qual}^{stop} = \frac{N_{board}^{pass}}{N_{alig}^{pass}} \quad \begin{cases} \text{if } e_{qual} < \vartheta \rightarrow option. \\ \text{if } e_{qual} \geq \vartheta \rightarrow fix. \end{cases} \quad (4)$$

If the value of Equation 3 is greater than or equal to the value of $\vartheta$, it should be treated as a fixed stop in the A-FTS design, and if it is less, it should be treated as an optional stop.
These data can be used to identify which sections and destinations are frequented and subject to high congestion.

### 4.2. B-FTS Flexibility parameters

When analysing B-FTS, the backbone and the flexible elements should be considered separately. The analysis of the backbone is similar to that for A-FTS, with the difference that the travel times will be influenced by the types of flexible elements in the system (sub-chapter 3.2) and their quantities. Each type of flexible element should be considered separately, as each element in the system may have a different impact on the variation of travel time and distance. Each elastic element can be classified at network level by the time, distance and number of optional stops affected by the by-pass trip.
On the practical side, the number of passengers carried will be essential for qualification. Need to select those types separately. It is possible for a passenger to board at a flexible stop on the backbone and travel to the destination, or to travel to a stop other than the backbone. Therefore, all the possible options need to be considered and the network elements can be classified as a result. For this flexible transport mode, not only the share of flexible elements is an important influencing parameter, but also the movements between fixed and optional network elements and the travel demand linking them. The application of B-FTS can be considered and applied effectively already for interurban and local trips. The size and capacity of a transport vehicle can have a significant impact on the quality of a flexible transport service, such as D2D passenger demand. Which can be effectively complemented by off-peak and low-capacity vehicles for passenger transport.

### 4.3. C-FTS Flexibility parameters

The C-FTS can no longer be characterised by the number of flexible elements. The mandatory network element may be the origin and the destination point, which are always located at the same physical location. This is a round trip-based concept, which can be studied using several logistical studies [10] [11] on round trip planning and service. In the design, it is necessary to define constraints on the size of the area served. A flexible transport system cannot cater for many trips on a single route/vehicle at the same time, as this would compromise the quality of the passenger service. These are specific parameters and have a major impact on the fare structure, the digital system for processing the demand and the service area. A similar problem is the separation of two types of activity for round services: collection and distribution. Time as an influencing parameter plays a limiting role in determining the volume of travel demand that can be served by a single service. On the other hand, for distribution and distribution services, the service quality indicator is the ratio between the number of trips carried and the number of trips collected. Which is not the same at different times of the day.

## 5. Further reaserch directions definition

As a result of processing the literature on the network elements involved in flexible transport systems, it was possible to outline structures that can be examined at a higher level and to establish them from a technical point of view. A large number of further research milestones and exploitations can be identified: (i) more detailed elaboration of the A-B-C-FTS categories from a research point of view; (ii) identification of the conditions for optimal planning of routes; (iii) development of a time-of-day dependent pairing strategy for a given transport system; (iv) development of decision-making relations for efficient organisation in public transport planning.

## 6. Conclusion

Mobility is an essential part of everyday life, which takes up a lot of time. Therefore, the study of travel chains is an important area of research and a key issue is to investigate the flexibility of mobility solutions. The efficiency of travel chains is strongly influenced using flexible and semi-flexible systems. Another advantage is that the use of flexible transport systems can identify latent mobility needs that are currently unknown.
To this end, this paper presents the parameters that influence the resilience of the established FTS categories.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# Logistics planning: Tasks, procedures and rules

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## Abstract
Logistics planning is a main discipline of the science of logistics. New trends and developments change requirements, approaches and solutions of logistics planning. The scientific problem is to check, identify, generate and document new and updated knowledge in this field. In this respect, the paper focuses on logistics planning tasks, on procedures, on trends and their effects, and on new or adapted rules of logistics planning.

## 1. Introduction
The identified research gap is in the knowledge of logistics planning. To this end, the research addresses and answers the following research questions:

1. Which logistics planning tasks can be distinguished?
2. Which approaches exist in logistics planning?
3. Which new trends and developments exist? How do they change and influence logistics planning?
4. What new knowledge on logistics planning can be derived from (3.)?
5. Which research questions regarding logistics planning need to be answered?

## 2. Methodology
The research is based on a comprehensive literature review combined with the authors' many years of expertise in the field of logistics planning and the evaluation of current research projects and trends. Well-known methods are applied. These are the morphological box, process description methods for the procedures of logistics planning, profiles for the trends and selected evaluation methods.

## 3. Results and Discussion
Overall, the following research results were obtained:

1. Morphological box for the characterization of logistics planning tasks.
2. Collection of established procedures of logistics planning.
3. Profiles of trends and definition of their impact on logistics planning.
4. Documented knowledge on new planning rules.
5. New research questions on logistics planning.

These research findings are excerpted and briefly explained below.

### 3.1. Result 1: Morphological box for characterization of logistics planning tasks
Logistics is a large scientific field and includes many tasks and new tasks are constantly added. This raises the question of a suitable systematization. A complete and consistent classification of all logistics planning tasks according to their content and subject matter is hardly possible and not known.

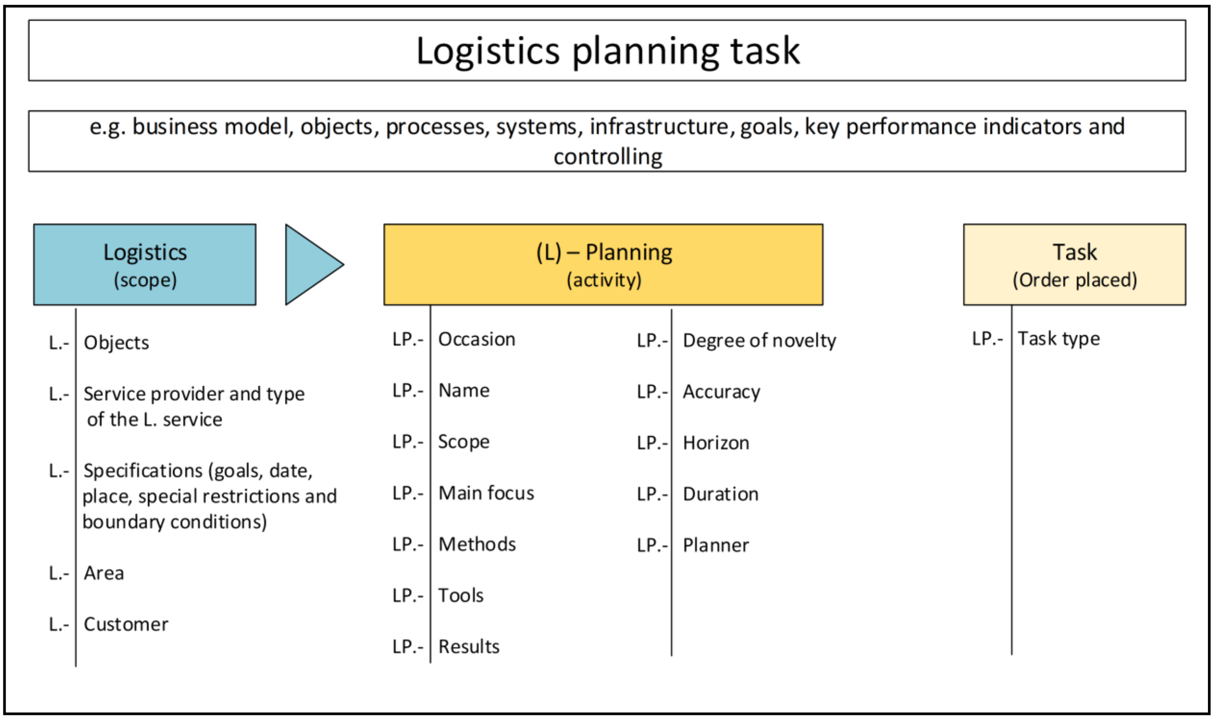


*Figure 1: Logistics planning task*

Existing scientific works work with exemplary task catalogues, e.g. Gudehus [1], with structuring models e. g. Pfohl [2] and Ziems [3] or limit the considered area first e.g. tasks of logistics planning in the automotive industry along the product development process e.g. Schneider [4], Schedlbauer [5]. In this paper (cf. Figure 1) the term "Logistics planning task" is subdivided into its three subwords: “Logistics” stands for the application area, “Planning” for the activity to be performed, and “Task” for the difficulty of the problem to be solved. Table 1 contains an attribute listing for the basic characterization of logistics planning tasks. Multiple entries in one row are also possible.

*Table 1: Attribute Listing for logistics planning tasks (open list)*

| **Attribute** | **Possible characteristics (examples)** |
|---|---|
| Logistics objects (Type of goods | General logistics goods<br>Persons as log. objects<br>Information as log. objects<br>General cargo; bulk cargo<br>Dangerous Goods<br>Art and museum goods<br>Refrigerated cargo<br>Heavy cargo<br>Special cargo<br>Express cargo |
| Logistics service provider and logistics service | 1PL, 2PL, 3PL, 4PL, 5PL<br>Type and scope of logistics activities |
| Specifications of the logistics provider | Goals<br>Places and dates<br>Requirements<br>Restrictions<br>Trends |
| Relevant Logistics part area (cf. [6], [7], [8]) | Supply Chain Management<br>Information logistics<br>Corporate logistics<br>(Industry, Trade, Service)<br>Procurement logistics<br>Production logistics<br>Distribution logistics and sale<br>Reverse Logistics & Disposal Logistics<br>Warehouse logistics and buffer<br>Traffic logistics<br>Transport logistics<br>Spare parts logistics and service<br>Inbound logistics<br>Intra logistics<br>Outbound logistics<br>City logistics<br>Military logistics<br>Hospital logistics<br>*Space logistics* |
| Logistics customer | Customer characteristics |
| Planning occasion (Reference to the life cycle of a planning solution) | ***Innovation***<br>Technological leaps<br>Market change<br>Product changes (logistic objects)<br>New construction<br>New design<br>Modernization, |

| | |
|---|---|
| | Hazard protection/<br>plant safeguarding<br>Rationalization<br>Reconstruction, change of use |
| | Requirements (authorities)<br>Organization<br>Malfunction<br>Expansion<br>Insourcing/outsourcing<br>Structural change<br>(e.g. relocation)<br>**Operation**<br>Deconstruction<br>Dismantling, demolition,<br>redevelopment |
| Planning name (Designation of the planning task (concrete designation of the object of planning, logistical problem) | Network planning<br>Site planning<br>General development plan<br>Structure plan<br>Material flow planning<br>Business process planning<br>Facility planning<br>Layout planning<br>Sequence planning<br>Route planning |
| Planning scope | Preparatory analyses<br>Task definition (specifications)<br>Concept (functional<br>specification)<br>Comparison and<br>-selection<br>Testing<br>Feasibility study<br>Implementation planning<br>Accompanying realization<br>Start-up planning<br>Evaluation<br>Remediation<br>Utilization |
| Planning focal points (planning area) | ***Business model***<br>Logistics object (goods, packaging, logistics equipment, loading unit)<br>Logistics processes (material, information, *financial and energy flows;* technologies)<br>Logistics system (*CPS*, MFS, IFS, FFS, EFS; network, factory to individual workstation)<br>Logistics infrastructure<br>(Technical, social, *green, blue*) |
| Planning methods and tools (defaults) | Key figure project planning<br>Model project planning<br>Modular project planning<br>Catalogue project planning<br>Planning software (algorithms (also ***AI, Big Data Analytics***, APS), MIS, BI, CAD, databases, |

| | |
|---|---|
| | project management,<br>simulation, VR, AR),<br>***Digital twin*** |
| Planning result (specifi-cations) | Documentation<br>(according to planning scope)<br>Calculation results<br>key figures<br>2D plan/drawing<br>3D model<br>Functional model<br>Animation<br>Simulation model<br>VR, AR<br>Video<br>*Digital twin* |
| Planning degree of novelty | Base technology<br>Improvement based on actual<br>Benchmarking (best practice)<br>Completely new target |
| Planning-accuracy | Rough (study)<br>Medium (standard plan)<br>Fine (Detailed plan,<br>execution) |
| Planning horizon | *Futurology*<br>*(science)*<br>Normative, value-based<br>Long-term, strategic<br>Medium-term, tactical<br>Short-term, operational |
| Planning duration (defaults) | long<br>medium (standard)<br>short<br>Real time |
| Planner (specifi-cations) | mainly internal<br>internal and external<br>mainly external |
| Task type (cf. [9], [10]) | Routine planning task<br>analytical problem<br>synthetic problem<br>dialectic problem |

Legend:

- Highlighted in *italics* = what is new.
- **Bold highlighted** = what is particularly important.

## 3.2. Result 2: Collection of established logistics planning procedures

There are various published approaches to logistics planning or approaches that are also relevant and useful for logistics planning.
Some important examples, recorded in an open list without claim to completeness, are:

- **Material flow planning** (7-step planning system according to [11].
- **Transportation planning** (4-step approach according to [12])
- **Site planning** (according to [13])
- **Product development** (design)
  - Problem solving cycle (according to Ehrenspiel [14]
  - VDI guideline 2221 (see [15])
- **Software planning** (computer science)
  - V-model (cf. [16])
  - Waterfall model [16]
  - Spiral model [16]
  - Scrum [16]
  - Kanban [16]
- **Packaging planning** 5 steps [17]
- **Investment planning**
  - 5 phases according to Olfert [18]
  - structured approach Ziems [19]
- **Factory planning**
  - 5 phases (based on [20]
  - Planning levels of factory planning (based on [21])
  - Procedure according to VDI 5200, sheet 1 [22]
- **Production planning** (production program planning, procurement planning, sales planning, scheduling and dispatching of operating resources, labour, material, tools and auxiliary materials; planning of lot sizes, throughput and capacity scheduling, sequence planning, detailed scheduling; dispatching and disturbance control)
  - task-oriented [23], [24], [25].
- **Project management** (project structuring, sequence planning, scheduling, resource planning, cost planning).
  - 4-phases (based on [26], [27], [28]
  - according to DIN 69901 [29], [30]
  - according to DIN 69909 [31]
- **Supply chain management** (cf. e.g. [32]) integrative and hierarchical approaches e.g. SC configuration, SC planning (sales planning, network planning, procurement planning, production planning, distribution planning, disposal planning, SC execution (scheduling and disruption management)
- **Logistics 4.0** (cf. [33], [34], [35]) Planning of logistics solutions according to the Smart Logistics Zone (business model, object, process, system and infrastructure)
- **Sustainability planning** (cf. [36], [37]) e.g., planning and optimization of compliance with laws and regulations, planning of waivers, planning of efficiency improvement, planning of new solutions, planning of compensatory measures.

Further examples are e.g. target planning, planning of analyses including forecasts, dimensioning (number planning), structure planning, warehouse planning, planning of digital factories, planning of order picking, financial planning and cost calculations, area planning, planning of function testing, batch size planning, planning of machine set-up and overall layout, scheduling, sequence planning, route planning, planning of collective runs, round trips and distribution runs as well as organizational planning.
Without reference to a specific planning task and its specifics, the logistics planning process can be generally described, for example, as follows:

- **Planning impulse**
- **Problem definition**
- **Specifying the task**
- **Target planning**
- **Planning and execution of analyses** (Determine and prepare planning data, elicit solution options)
- **Planning of the target solution**, if necessary in variants
  - Planning of business models, logistics objects, processes, structures, systems, infrastructures and organizations
  - Establishment and exclusion of alternatives
  - Evaluation and decision-making regarding the best alternative
- **Detailed planning**
- **Implementation planning**
- **Planning implementation support**
- **Planning in operation**
- **Accompanying and final evaluation**

Due to the diversity and complexity, the formulation of a general, standardized procedure for every logistics planning task is not feasible. In this sense, the described procedure should only provide a basic orientation. Details and the individual approach as well as the methods and tools used have to be adapted specifically to each individual case.

## 3.3. Result 3: Fact Sheets for Trends and Impacts on Logistics Planning

To answer the research question: What new trends and developments exist? these were first researched in the literature. (cf. among others [38], [6]).
In this paper, the so-called DHL trends are used for the sake of clarity. (cf. [38])
Then, the question was investigated: How do the trends and developments change and influence

logistics planning? For the evaluation of the influence an evaluation scheme was established. Figure 2 shows the relevant evaluation aspects. The upper part of the picture (marked in orange) shows the components of the logistics solution. The left side of the picture (marked in yellow) illustrates important input variables of the planning. In the middle part (marked in grey), the actual planning is characterized on the basis of five formative aspects. The right part of the picture (marked in turquoise) is dedicated to the planning results and the evaluation.
Tables 2 and 3 show results and contain important current trends and their impact on logistics planning using the systematics of Fig. 2.
The symbols in tables 2 and 3 have the following meaning:
* = noticeable influence
X = great influence
**X** = determining influence

Note: The evaluation of the influence on logistics planning in tables 2 and 3 corresponds to the subjective opinion of the authors and their scientific environment. This evaluation is hereby put forward for broad scientific discussion.
After individual evaluation and ordering of the trends, the following patterns and thus groups become visible. They have been marked in color. In addition, the corresponding changes can be read off column by column.

The influences should be considered in order to generally meet the changed requirements and opportunities (effectiveness), but also to make planning efficient. This concerns the reduction of the planning effort, the improvement of the planning quality and the increase of the planning speed. From the tables 2 and 3 the influences on logistics planning can be read out and verbally summarized.

A few examples will be given:
(1) With regard to the logistics object, it can be seen that it is becoming more intelligent and autonomous. One example is smart containerization. Another important trend is Rethinking Packaging.
(2) Infrastructure is becoming more important for finding solutions. For example, the presence of 5 G networks is crucial for certain logistics solutions based on image processing or Big Data analytics.
(3) Energy aspects should increasingly be considered. For example, decentralized solutions such as cargo bike depots or autonomous conveyor technology also require a functioning energetic solution.
(4) The boundaries between material, informational, organizational and energetic solutions are becoming blurred and cannot be clearly assigned in some cases. Examples include cyber-physical systems where, for example, sensors serve multiple flows.
(5) There are some new target and evaluation categories for logistics that complement the classic parameters such as cost, time and

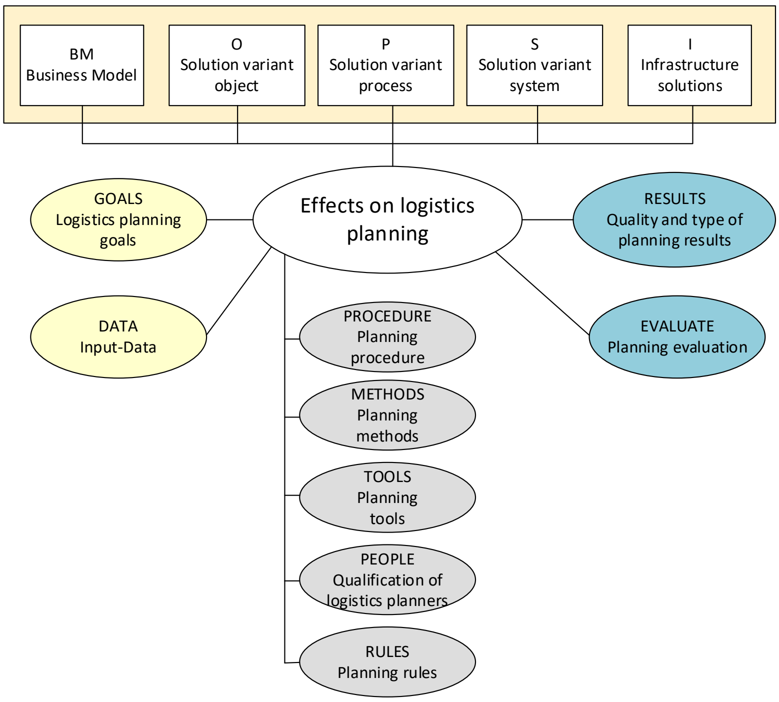


*Figure 2: Relevant effects on logistics planning*

*Table 2: Influence of social & business trends according [38] on logistics planning*

| Social & Business Trends [38] | Influence on logistics planning (own work) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IN | | SOLUTION | | | | | PLANNING | | | | | OUT | |
| Own work: clustering | GOALS | DATA | B-MODEL | OBJECT | PROCESS | SYSTEM | INFRA | PROCEDURE | METHODS | TOOLS | PEOPLE | RULES | RESULTS | EVALUATE |
| Supergrid Logistics | | | **X** | | | | | | | | | | | |
| Logistics Marketplaces | | | **X** | | | | | | | | | | | |
| Sharing Economy | | | **X** | | | | | | | | | | | |
| Servitization | | | **X** | | | | | | | | | | | |
| Silver Economy | | | **X** | | | | | | | | | | | |
| Space Logistics | | | **X** | | | | | | | | | | | |
| Multisourcing | | | | | **X** | | | | | | | | | |
| Omnichannel Logistics | | | | | **X** | | | | | | | | | |
| Mass Personalization | * | X | **X** | X | **X** | X | | | | | | X | | X |
| Fresh Chain | | | * | | **X** | * | | | | | | | | |
| Smart Containerization | | | | **X** | X | | | | | | | | | |
| Rethinking Packaging | * | | | **X** | | * | | | | | | | | * |
| Sustainable Logistics | **X** | * | * | * | * | * | * | * | X | * | * | * | | **X** |
| Next-Generations Security | **X** | X | * | | * | X | | X | X | X | X | X | | **X** |
| Future of Work | * | | | | | * | | | | | **X** | | | * |

*Table 3: Influence of technology trends according [38] on logistics planning*

| Technology Trends [38] | Influence on logistics planning (own work) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | IN | | SOLUTION | | | | | PLANNING | | | | | OUT | |
| Own work: clustering | GOALS | DATA | B-MODEL | OBJECT | PROCESS | SYSTEM | INFRA | PROCEDURE | METHODS | TOOLS | PEOPLE | RULES | RESULTS | EVALUATE |
| Self-Driving Vehicles | | X | * | | X | **X** | X | X | | | * | | | |
| Unmanned Aerial Vehicles | | X | X | | X | **X** | X | | | | X | | | |
| Robotics & Automation | | X | * | | | **X** | X | | | * | | | | X |
| Bionic Enhancement | X | * | X | | | **X** | * | | X | | X | X | X | X |
| 3D Printing | | | * | | **X** | **X** | | | | | | | | |
| Artificial Intelligence | | X | * | | | x | | X | **X** | **X** | X | | | |
| Big Data Analytics | | X | * | | | | | X | **X** | **X** | X | | | |
| Augmented & Virtual Reality | | | * | | | | | X | **X** | **X** | X | | **X** | X |
| Internet of Things | | | * | * | X | **X** | X | | X | X | X | X | X | X |
| Next-Generation Wireless | | | | | | **X** | **X** | | | | | | | |
| Blockchain | | | * | * | | **X** | | X | X | * | X | X | X | |
| Cloud & APIs | | | | | | * | * | X | | **X** | | | | |
| Digital Twins | * | X | * | | | X | | X | * | **X** | * | * | **X** | X |
| Quantum computing | | | | | | | | | | **X** | | | | |

quality. These are e.g. sustainability and safety, but also scalability and adaptability.

(6) The use of digital technologies is changing the planning process. This concern, for example, the use of techniques such as virtual reality (VR), augmented reality (AR), data storage in the cloud or distributed project work. Engineering takes place in the cloud, including simulations. At the same time, the requirements for the qualification of logistics planners are changing.

## 3.4. Result 4: Documented knowledge of planning rules

There are already rules for logistics planning processes in the literature. (e.g. [39], [40])
The updated knowledge includes, for example, current recommendations for logistics planning. (cf. Table 4). Table 4 contains some examples for the business model, for logistics objects and for logistics processes to illustrate changed rules.

*Table 4: Examples of new recommendations for logistics planning (business model, logistics objects and logistics processes only)*

| Planning focus | Explanation |
|---|---|
| Business model | ***Consider new business models Define the logistics portfolio e.g. driven by innovation and opportunities (expand, adapt or redefine business models).*** |
| Logistics objects | Form purposeful units (e.g. procurement unit = production unit = transport unit = storage unit = packaging unit = shipping unit = trading unit) or ***plan a minimal effort order picking.*** |
| Logistics objects | Classify logistics objects to simplify and reduce the planning effort. |
| Logistics objects | ***Decide on the intelligence of objects*** *and test the use of intelligent objects (Identification, Localization, Data Collection, Data Processing, Data Storage, Communication skills, Making decisions).* |
| Logistics objects | ***Pay attention to sustainability and security of logistics objects.*** Use, protect, secure and design sustainably according to requirements, processes and systems (part, product, packaging, loading unit, service). |
| Logistics processes | ***Define a new ideal of the process:*** *effective, efficient, safe and sustainable.* |
| Logistics processes | **Plan material, information**, ***financial and energy flows equally.*** |
| Logistics processes | **Test all four approaches to process planning if possible**: Known basic processes, Kaizen (improve as-is), Business Reengineering (new to-be) or Benchmarking (reuse best performance). |
| Logistics processes | ***Question new solutions for processes*** *with regard to goals, trends, sustainability, value and waste, freedom from errors, automation, digitalization and networking, potentials, weaknesses, ergonomics, focus, Corporate culture and controlling.* |
| Logistics processes | **Define clear and consistent process goals, standards, rules, measurement points and metrics.** |
| Logistics processes | **Pay attention to disruptions and risks** in planning, "normal operation" is always also subject to disruptions and latent risks. |
| Logistics processes | **Tests process structures and sub-processes** (e.g. bundling, integration, parallelization, splitting, extending, shortening, eliminating, differentiating, swapping). |
| Logistics processes | **Define clear processes** (e.g. fetch, bring, control centres, decentralized control, stations) or ***allow decentralized degrees of freedom.*** |
| Logistics processes | ***Set up measurement points for tracking and tracing.*** |
| Logistics processes | **Design main processes** (material) and **secondary and integrating processes** (e.g. waste products) in an equally effective, efficient, ***safe and sustainable manner.*** |

Legend:

- Highlighted in *italics* = what is new.
- **Bold** highlighted = what is particularly important.

## 4. Conclusion

The research work will contribute to basic research in the field of logistics planning. It will subsequently be used in education and training and as a basis for various research projects in logistics. New research questions will be raised.

For example, there is still a considerable need for research in the area of delimitation, definition and classification of planning tasks. Furthermore, the question arises, which new planning rules can be established?

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# Packaging management system based on digital technology

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## Abstract

Choosing the right packaging and upgrading existing packaging systems is a growing challenge in industry practice, mainly due to the significant expansion of product structures, the rise of e-commerce and the variety of seasonal packaging. In the article, the literature related to the topic will be reviewed, and then the operating principle of the concept of a packaging management system will be presented, which supports the review and continuous improvement of the packaging system already established at the company's site. The packaging management system concept is presented in 3 main parts. These are: selecting the right packaging for a new product, proposing packaging improvements for an existing product, and checking packaging using digital twin technology. This paper presents a systematic literature review of the field under study and the 3 main areas of the packaging management system we have identified, with a process description. This study summarizes the initial results of a PhD research. In the future, a detailed conceptualization of the 3 areas identified is planned. This publication is a summary of the results achieved so far.

## 1. Introduction

Digital twins have already been used in many areas, but there are still significant applications in logistics. This paper based on our previous publication [1], in which the potential applications of digital twin technology in logistics were analyzed and an important research direction for digital technology was identified. This research area includes the packaging management, due to the topicality of the topic, the lack of adequate research on the subject, and the personal motivation which based on the interest of the postgraduate specialist packaging development engineer training at the Institute of Logistics of the University of Miskolc. In the industrial practice, the selection of appropriate packaging and the improvement of existing packaging systems are becoming increasingly challenging, mainly due to the significant expansion of product structures, the rise of e-commerce and the variety of seasonal packaging [10,15]. Thus, a literature review was conducted to explore the aspects of the international literature that have been covered in this area. Databases and keywords were identified for the study. This databases Scopus and ScienceDirect were used for the research.

Applied keywords:

- „digital twin" AND „packaging" AND „logistics"
- „packaging management" AND „logistics"

For the literature research, searches were started using the defined keywords. Reduce the Scopus database to the first search keywords were the following: title, abstract, keywords which resulted in a single search hit, while increase the search on all fields resulted 85 articles. Using the ScienceDirect database, the first search keywords listed 272 publications. For the second search, which was for the keywords: packaging management and logistics, resulted 107 publications in Scopus, while ScienceDirect resulted 57. The research was made in March 2022, from the year 2000 to 2021. On the Figure 1, you can see the results of this analysis. The articles based on the packaging management systems have been published so far covered the entire supply chain, such as article [16].

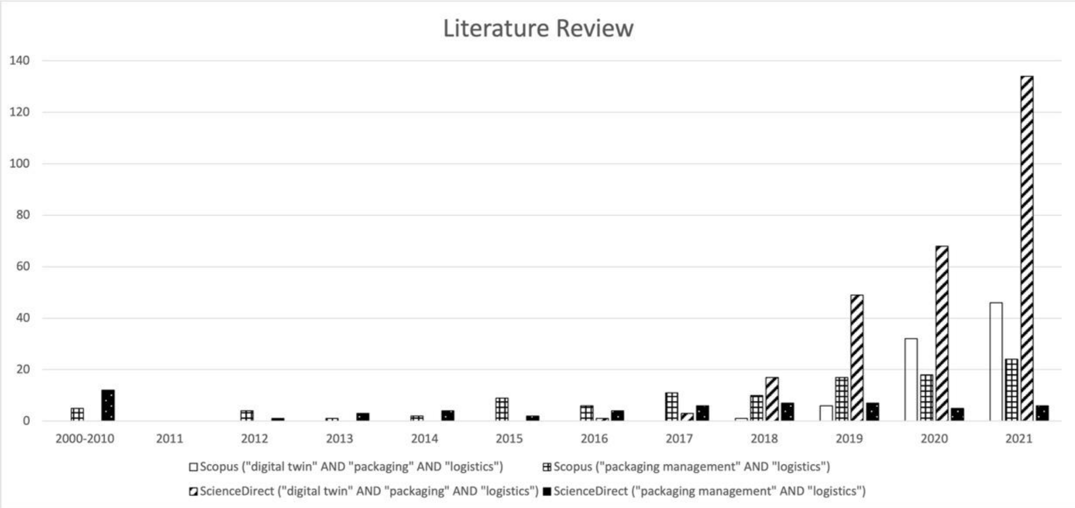


*Figure 1: Literature review results*

Furthermore, the articles so far have typically been product specific, such as [17], where the food supply chain and intelligent packaging are presented, with implications for food. The Scopus-indexed publication [6] deals with a reliability model that analyses sensor data from packaging systems and discusses the IoT (Internet of Things) model generated from sensor data [6]. Although this paper mentions the lack of research on the development of digital twin and digital technologies, it does not detail it. The journal [2] deals with the use of automotive packaging, where comparisons of different sustainable packaging systems are presented, but does not deal with the digital technologies and their benefits of use. The journal [7], published in 2021, deals with the generation of packaging waste and its importance. This publication explains that research on the product-packaging supply chain is still in its early stages. Our aim in this paper is to investigate and present the digitization aspects of the logistics packaging field. Due to its many advantages, the industry is increasingly preferred returnable packaging, but this advantage can only be fully used if the system is properly managed. The aim of the present study is to create models that allow the investigation of different packaging systems and the selection of the appropriate packaging system. Reusable transport packaging such as pallets, trays, crates or refillable liquid and gas cylinders play an important role in modern logistics. The use of these products in the supply chain can bring several benefits, including reduced packaging and waste, better protection and security of products, more efficient handling, better possibilities for outsourcing, combining and standardization moreover lower $CO_2$ emission over the life cycle of the packaging material [2].

## 2. Packaging management system concept

The loss reduction opportunities available in the field of packaging management, as well as several external forces are pushing companies to make a greater effort in this direction. Examples of relevant impacts are changes in consumption patterns, lengthening of supply chains, new materials and technologies, environmental protection, regulation, and corporate responsibility obligations. The best possible management response to these complex operating environments will come about through the interaction of several functional areas within the company, representing different aspects, combining, and integrating in different ways at different times. This is a large and increasingly important element of complex management [3].
Packaging is an integral part of modern life. Due to the large quantities of packaging materials used and the ease of recovery, the reuse and recycling of packaging waste has become a top priority for the European Union. The aim of recycling waste is to recycle it [4].
Individualized design of mass custom manufacturing systems is difficult, as it involves adaptive integration of both new and old machines to create unstable families. A systematic virtual model that reflects the real world of the manufacturing system is essential to bridge the gap between design and operation of manufacturing systems. A digital twin-driven solution makes design faster and more customizable [5]. The digital twin combines physics-based system modelling and distributed semi-physical simulation to provide engineering solution analysis capabilities and create a credible digital design of the system in the pre-production phase. Realistic process models are essential to enable early and effective evaluation of design decisions, both in terms of product quality and

system performance. Computer-aided simulation tools play a significant role as they deal with the validation of manufacturing systems. One promising approach to address complex problems is the digital twin, which realizes the interplay between the physical world of manufacturing and the cyber world [5].
The digital shadow integrates data from all available sensors and IT systems into a single virtual representation, including the display of all associated services [18]. Packaging development is more efficient with the use of digital shadow.
The use of digital twin technology can facilitate the development of lighter, more environmentally friendly packaging materials. To improve sustainability, companies are exploring the use of a range of new materials, including recycled materials. Companies not only need to manage transportation, but also control damage and contamination that could compromise future cargoes [8].
The optimal choice of packaging has a wide meaning that extends to the manufacturing and logistical processes within the manufacturing plant. Properly selected packaging is an essential link in the entire logistics chain. It performs a few functions from the production line to the point of delivery to the customer and storage. The most common types of cargo are small, requiring packaging that is durable, spacious, and properly sealed, thus facilitating the logistics of the manufacturing process. Reusable packaging has become the common standard because it is practical and economical [9].

## 2.1. Structure of a packaging management framework

Figure 2 shows the structure of a packaging management framework that will be developed later. To create the system, it is necessary to clearly define the study participants, the most important tools, databases, and the connections between them. Based on Figure 2, the framework can be divided into three parts. The study participants are the experts, the management, the research and development (R&D) team and the information providers.
**Experts:** The experts are fully familiar with the packaging management system and carry out the necessary tests. Their tasks include a thorough knowledge of the three main areas, these are: selecting the right packaging for a new product, selecting the right packaging for an existing product, and testing packaging to eliminate quality defects. They will also be responsible for data collection, data processing and evaluation tasks according to the type of test selected. The use of software and simulation programs supporting the packaging management system is also part of the scope of the duties.
**Management:** Management sets the development guidelines. Its task is to make strategic and tactical decisions, to negotiate with new companies and to conclude contracts based on the recommendations of experts.
**R&D group:** The R&D group develops the methods and procedures approved by management and required for testing.
**Information providers:** Information providers are those who provide the additional information needed to perform the study. In the first place, the data, and parameters of the possible packaging systems for a product are given to the needs of the experts.
The most important tools related to the system are the simulation software, sensors, and cameras.
**Simulation software:** The events belonging to the planned packaging system are investigated using a discrete event-driven simulation framework. This allows the virtual model of the plant to be combined with real plant control for the actual simulation [11]. Thus, the complete operation can be tested and optimized. With the discrete, event-driven simulation system, it is possible to improve and simulate logistic processes, optimize material handling, machine utilization and labour demand

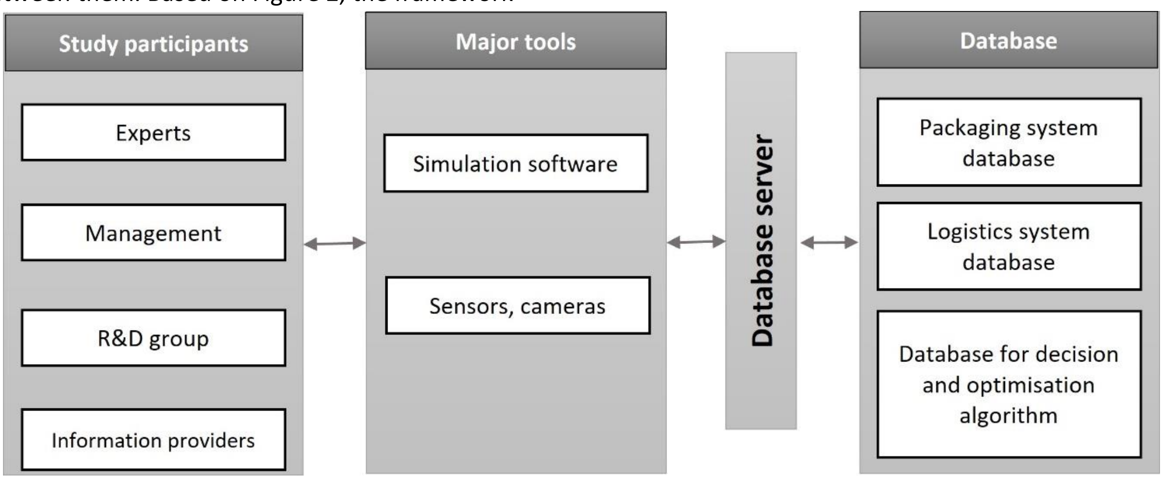


*Figure 2: Structure of a packaging management framework*

with statistical analysis capabilities. The use of object-oriented tools with 3D modelling capabilities can increase manufacturing accuracy, efficiency, and improve throughput and system performance [12]. Simulation processing begins with a preliminary analysis to identify problems, and then simulation plans, checks, and validations are created to create them. After collecting and examining the data of the packaging materials, the software process them, so the problem is identified, and simulation plans are created [13].

**Sensors, cameras:** Other important tools are sensors and cameras. In some cases, it is necessary to collect and manage data from the real system and based on this data we can propose a better, more efficient system, and we can also propose how to detect and manage quality defects when inspecting packaging.

Figure 2 shows that the database consists of 3 main parts, these are: the databases of the packaging system, the databases of the logistics system, and the databases belonging to the decision and optimization algorithm.

**Database of packaging systems:** Contains the data necessary for the design and implementation of the packaging system.

**Logistics System Database:** Contains input data that is important for testing.

**Decision and optimization algorithm database:** Contains the objective functions required for decision and optimization. It is recommended to use a decision method if a new system with one type of packaging is developed and if a new packaging system is chosen for the existing system. We can talk about optimization if we want to design a packaging system for several variables and different products.

A new method of database management is Big Data Analysis. Big Data management aims to ensure a high level of data quality and availability for business intelligence and Big Data analytics applications. Efficient big data management mainly helps companies to find valuable information from a large set of different unstructured and semi-structured data. As part of managing Big Data, companies need to decide what data they want to retain, discard, or analyse for compliance reasons to improve processes. Thus, the process requires data classification, and smaller data sets can be analysed quickly and efficiently [14].

Our idea about the basic concept structure has been designed so that any company can adapt to its own needs after providing the appropriate data. You can choose from three main areas depending on whether you want to do new packaging, upgrade your existing one, or fix bugs. In our

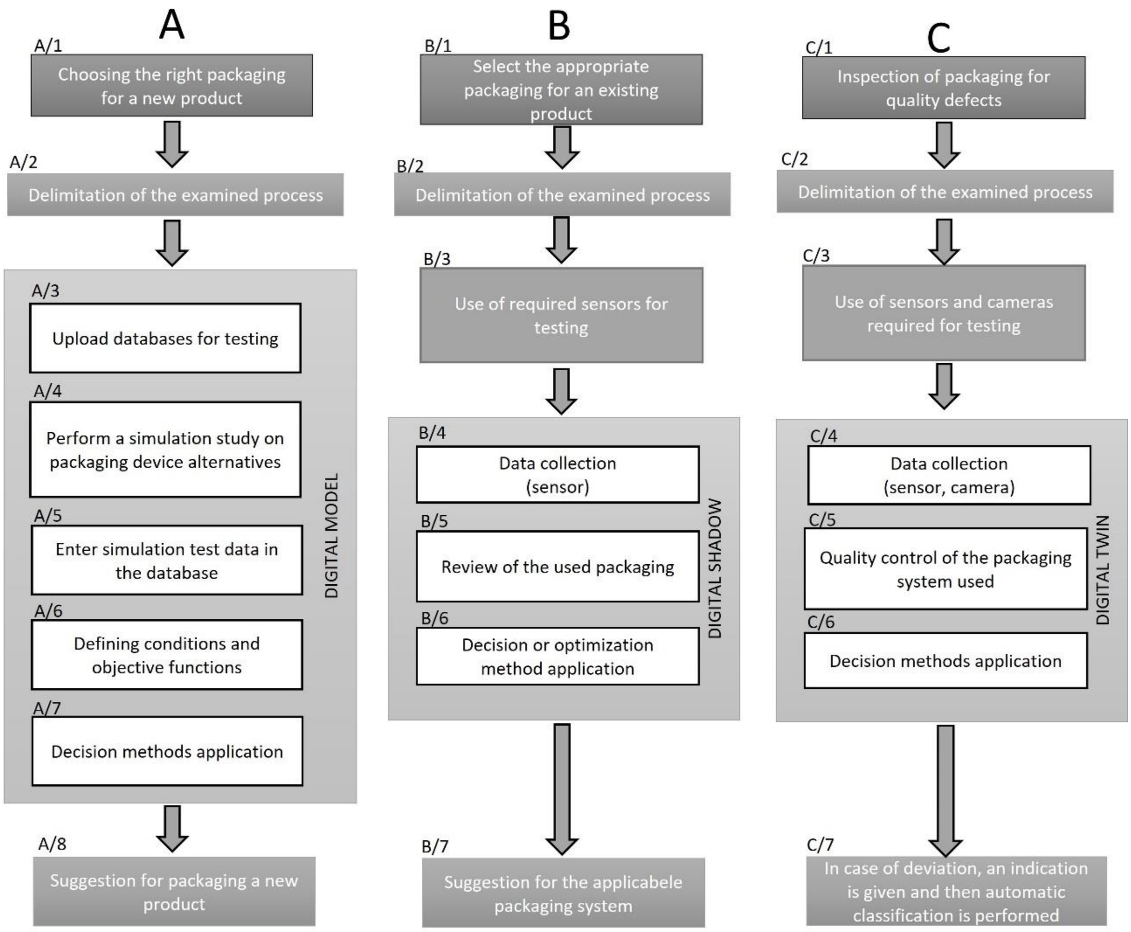


*Figure 3: Important steps of the application of packaging management system*

opinion, this is a suitable system for improving packaging. Our plan is to work out this in detail.

### 2.2. Important steps of the application of packaging management system

The article develops the concept of a packaging management system, the function of which helps to select and improve the packaging system and to ensure the quality of the applied packaging system in relation to the designated logistics process. The developed packaging management system can be divided into three main components, which are shown in Figure 3.

When selecting the appropriate packaging for a new product, a simulation test model is developed that, after uploading the data related to the packaging system alternatives, produces the data needed to select the appropriate alternative. These include lead times, operating costs, maintenance costs, and so on. This is illustrated by the model marked “A”. After defining the process to be examined, databases will be uploaded. Then we examine the alternatives with the simulation test. After that, the target functions, and conditions for selecting the packaging system are selected, and finally we make a proposal for the packaging of the new product.

When selecting the appropriate packaging for an existing product, a simulation model is created that simulates the packaging of the currently operating system. During the simulation, the system reviews and then makes suggestions for optimization. This is illustrated by the model marked “B”. In this case, the delimitation of the examined process is also the first step, and then sensors are used for the examination, which help the data collection. Using digital shadow, deciding on the suitability of your current packaging is the next step. With digital shadow, data collection is automatic from the used sensors. Finally, make a proposal for the packaging system.

Examination of the packaging to eliminate quality defects, cameras and sensors are used to examine the current system, and then a simulation test model is created. This is described in the model marked “C”. After delimiting the examined process, sensors and cameras are used, by which the data collection is automatic. The inspection of the packaging management system eliminates and prevents quality defects. In the event of a fault, the system signals and, if necessary, a light and/or sound and/or automatic classification is performed.

## 3. Conclusion

The publication presented an initial concept of a packaging management system whose research needs were grounded in a detailed literature review [1]. The literature analyses results showed that the number of articles published has grown over the years, but there are still many opportunities in this area. The publication presents a short excerpt of an innovative concept in the field of packaging management systems, based on an industry 4.0 toolkit. The system presented combines digital twin, digital shadow, and digital model solutions at the same time. After outlining the scientific gap and the concept, we plan to implement the practical development and implementation of the individual subsystems in the next phase of the PhD research.

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# Design of the manipulator control system for charger complex for electric vehicles

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## Abstract

The number of electric cars in the world is growing. Many analysts believe that a new era is beginning, in which electric cars mark the end of the oil era. However, despite the popularity of this alternative mode of transport, the age of "black gold" will continue for a long time, the other side is sure. Unlike traditional cars with internal combustion engines, electric cars can be refuelled wherever there is access to an electrical outlet. This facilitates infrastructure development. In addition, ongoing experiments with electric vehicle charging options show the prospects for new ways of charging, such as wireless charging in parking lots or traffic lights.

Electric cars are gradually gaining popularity, but in order to be used nationwide, appropriate infrastructure is needed. The main problem of electric cars is their operational difficulties associated with the duration of travel on a single charge and low infrastructure under them. This is what prevents the full transition to this mode of transport.

At present, different countries have different government programs to encourage both citizens to buy electric cars and entrepreneurs to develop charging station networks.

Automated charging station systems are also gradually evolving. There are already charging station terminals with payment by bank card and other payment systems, but they operate on a self-service basis. To fully automate the charging process, it is not enough to connect the charging station to the electric car without human intervention. Wireless charging solves this problem, but at this stage of development, the power transmitted in this way is not always enough.

The solution to this problem can be the installation of a manipulator arm on the charging station. The manipulator will determine the position of the car and insert the charging station socket into the machine plug, using sensors and machine vision.

## 1. Introduction

Electric cars are treated as the latest technology in the automotive market. Despite the fact that all developed countries are trying to switch to "green" electric car systems, interest in these vehicles around the world is still low. An important issue for electric vehicles is the availability of adequate charging infrastructure, as waiting at charging stations due to lack of chargers may deny owners of electric vehicles [1, 2].

With each passing month, the number of electric vehicles in Ukraine is growing [3], which brings to the fore the development of charging infrastructure. As of December 1, 2021, there were 32,662 electric vehicles in the country - an increase of 845 units or 2.6 % compared to the previous month. This is a very good pace, which is maintained almost throughout 2021. Increase in four months - 3.2 thousand cars.

According to the marketing agency IRS Group, as of September 2020, there are 8529 in Ukraine points of electric charging stations. The ratio of the number of electric vehicles to the number of points the connection is 4.2. This is a very good indicator, at the level of the best European countries (same index in the Netherlands). At the moment, the big three have formed in Ukraine players of electric charging infrastructure are AutoEnterprise, EcoFactor and TOKA.

A large share of the Ukrainian market of charging stations is occupied by the Kharkiv company AutoEnterprise, which manufactures charging stations, operates its own charging network, and also imports electric cars. AutoEnterprise produces commercial charging stations (including high-speed), as well as complexes that can charge up to 5-6 cars at a time. About a third of the chargers are manufactured for the domestic market, the rest - for foreign companies. AutoEnterprise works within the framework of the white label concept, i.e. chargers manufactured by it are used under the company's brand around the world. In addition, AutoEnterprise itself develops electric vehicles - trolleybuses, tractors and ATVs.

Thus, electric cars can achieve significant energy savings, be part of urban planning, which includes sensors and new communication technologies (e.g. parking, traffic management), and, more importantly, be part of "Electric Mobility" - the main strategy for smart city reduction to reduce emissions from road transport and improving the resilience of cities, which in turn will contribute to the sustainable development of the country as a whole [4, 5].

This development is relevant because the network of infrastructure for electric cars is currently being actively developed and expanded [6]. The need for automation of gas station filling stations increases

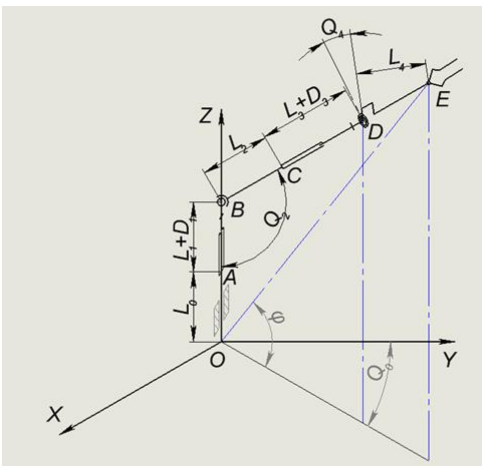


*Figure 1: Kinematic diagram of the manipulator*

with their number. Automation technologies are becoming more affordable and cheaper [7]. Developments in this area are underway, but not actively enough, as long as they remain within the framework of expensive concepts and only a few companies.

The research is devoted to the design of the manipulator control system for the charging complex of electric vehicles of the company AutoEnterprise.

## 2. Experimental part

### 2.1. Development of the kinematic scheme of the manipulator and its control system

For the manipulator it is necessary to provide sufficient kinematic freedom of movement to cover the working area of the charging station, but not to complicate the design [8]. The developed kinematic scheme is shown in Figure 1.

Next, to determine the position of the manipulator in the workspace, the direct and inverse problems of kinematics for this scheme were solved. The result of solving the problems of kinematics is presented in the form of equations:

(1) $X5_x = A5_{0,0} = -\sin(q_0)\cdot\sin(q_4) - \cos(q_0)\cdot\cos(q_4)\cdot\sin(q_2);$

(2) $X5_y = A5_{1,0} = \cos(q_0)\cdot\sin(q_4) - \cos(q_4)\cdot\sin(q_0)\cdot\sin(q_2);$

$X5_z = A5_{2,0} = -\cos(q_2)\cdot\cos(q_4);$

(3) $Y5_x = A5_{0,1} = \cos(q_0)\cdot\sin(q_2)\cdot\sin(q_4) - \cos(q_4)\cdot\sin(q_0);$

(4) $Y5_y = A5_{1,1} = \cos(q_0)\cdot\cos(q_4) + \sin(q_0)\cdot\sin(q_2)\cdot\sin(q_4);$

$Y5_z = A5_{2,1} = \cos(q_2)\cdot\sin(q_4);$

$Z5_x = A5_{0,2} = \cos(q_0)\cdot\cos(q_2);$

$Z5_y = A5_{1,2} = \cos(q_2)\cdot\sin(q_0);$

$Z5_z = A5_{2,2} = -\sin(q_2);$

(5) $P5_x = A5_{0,3} = \cos(q_0)\cdot\cos(q_2)\cdot(d_3 + l_3) + \cos(q_0)\cdot\cos(q_2)\cdot l_2 + \cos(q_0)\cdot\cos(q_2)\cdot l_4;$

(6) $P5_y = A5_{1,3} = \cos(q_2)\cdot\sin(q_0)\cdot(d_3 + l_3) + \cos(q_2)\cdot\sin(q_0)\cdot l_2 + \cos(q_2)\cdot\sin(q_0)\cdot l_4;$

(7) $P5_z = A5_{2,3} = d_1 - \sin(q_2)\cdot(d_3 + l_3) - \sin(q_2)\cdot l_2 - \sin(q_2)\cdot l_4 + l_0 + l_1.$

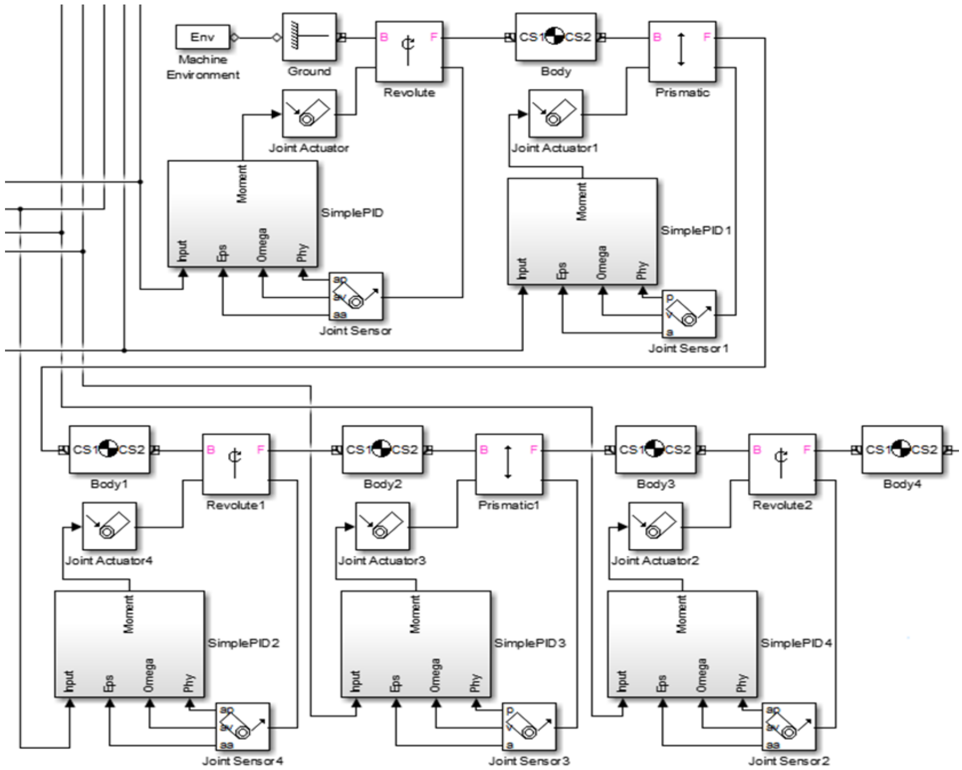


*Figure 2: Block diagram of the connection of servomotors and PID controllers with manipulator links and control unit*

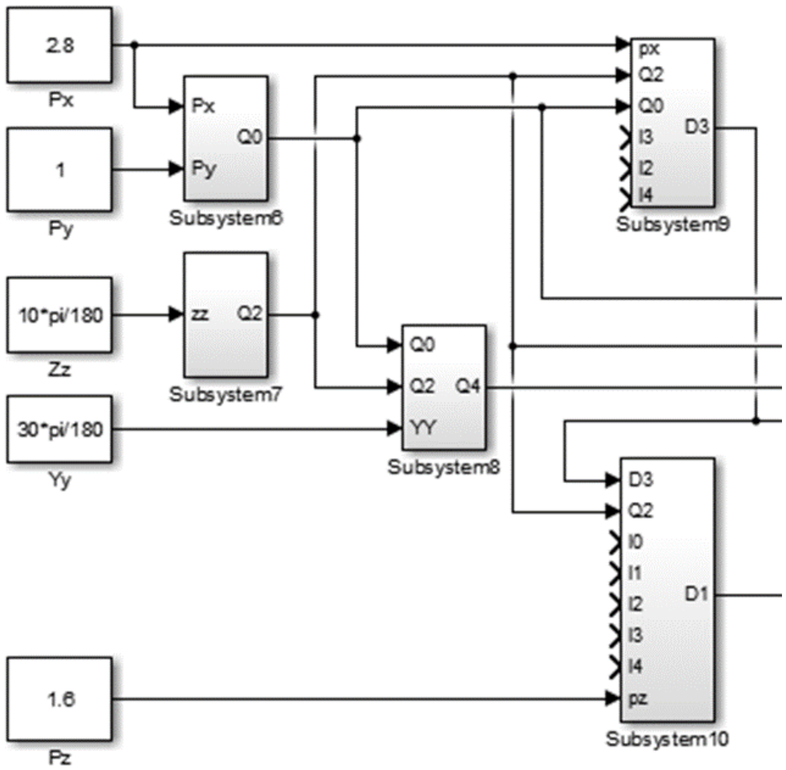


*Figure 3: Block diagram of the control unit of the manipulator*

The MATLAB application software package simulated a physical model of the manipulator together with servomotors, PID controllers and a control system based on the equations of kinematics problems. The result of the simulation was a block diagram (Figure 2 and 3)

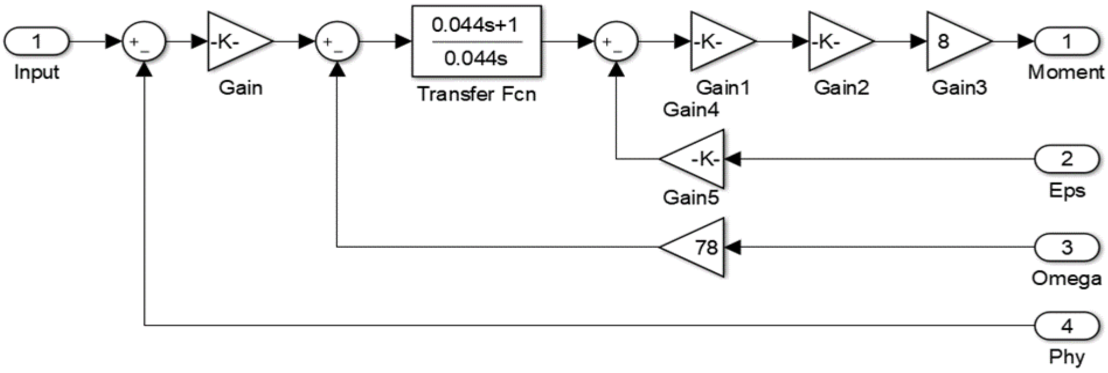


*Figure 4: Block diagram of the PID controller*

Selection of electronic components and software
For a full-fledged control system of the automated charging station it is necessary to implement systems of machine vision and protection. For machine vision we use Raspberry Pi Zero, Pi camera, cable loop, microSD card, USB power supply, USB-microUSB cable. The machine vision system will ensure that the car's charging connector is located in the working area of the station. Pulse distance sensors (RPT) and the TL725 "MEMS" gyroscope with integrated three-axis accelerometer will provide accurate position tracking and control of charger movement. The integrated CPS servo drive combines everything necessary to control the movement of the motor rotor in different operating modes in one compact housing. A PID controller is used to control the manipulator drives. It forms a control signal, which is the sum of three terms, the first of which is proportional to the difference between the input signal and the feedback signal (mismatch signal), the second - the integral of the mismatch signal, the third - the derivative of the mismatch signal.

The PID controller model is built using the MATLAB software package (Figure 4). Simulation of the PID controller is shown in Figure 5.
As the protection system of the switching device the own design of the protection device at arc breakdown (PDAB) is used (figure 6). The scheme of the control system will be based on the scheme of PDAB with the bipolar mechanism of the automatic switch.

The following sensors were used to determine and control the parameters of the power circuit of the charging complex:

- current sensor (Hall sensor) to measure the current in the circuit due to a change in magnetic field;
- temperature sensor (circuit with thermal converter) for measuring the voltage in the circuit through the temperature of the conductor (Figure 7).

The sensors are connected to a microcontroller that is powered by a switching power supply. The microcontroller uses a thyristor key to disconnect the power circuit. Similarly, electromagnetic and thermal disconnectors disconnect the power circuit when critical values are reached.
For the implementation of this scheme, two Hall sensors huaibei huadian HD-T10IC3, three normalizing amplifiers LM386 Arduino (11171), automatic release ABB S803B-B80 type B, automatic switch BA88-35R 3P 125A 35kA, thyristor 12T and 5 A, Arduino Uno R3 CH340 microcontroller.

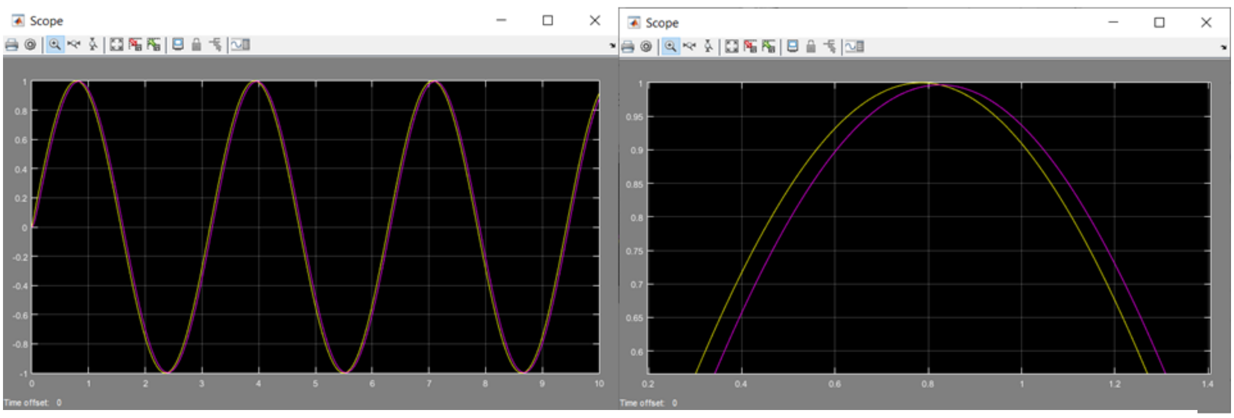


*Figure 5: Schedule of the PID controller*

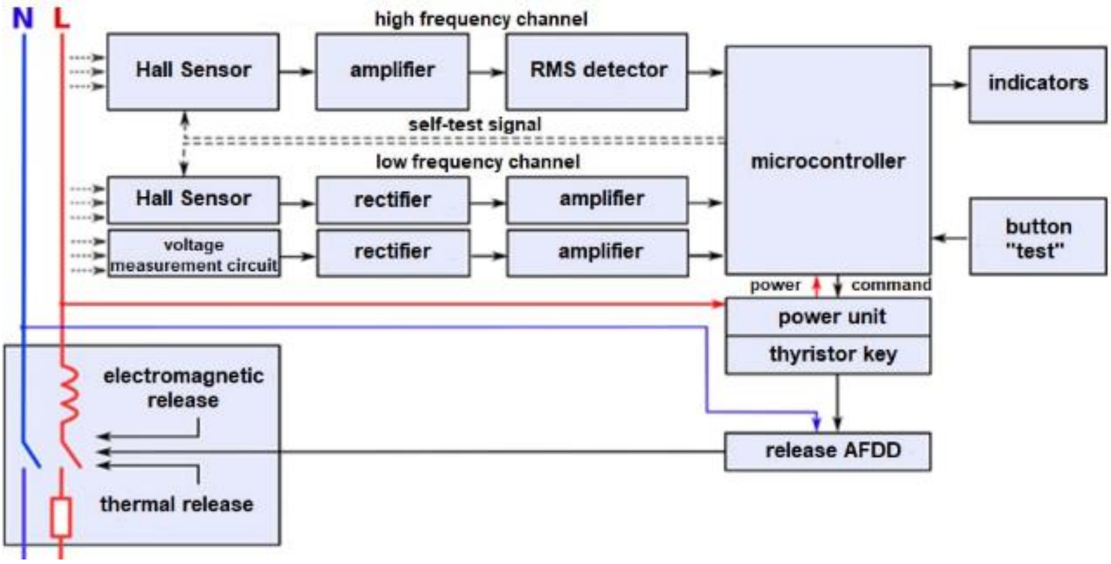


*Figure 6: Block diagram of PDAB with bipolar circuit breaker mechanism*

### 2.2. Arrangement and principle of operation

A developed manipulator with built-in sensors, a controller and a protection system for the switching device is connected to the charging station (Figure 8).

The system aims to automate the process of charging an electric car. The designed system is used according to the following principle:
first step: the car approaches the working area of the charging station;
the second step: in the mobile application we initiate the start of charging by making a payment. If everything is done correctly, the machine's vision will determine the position of the charging connector of the electric car, then with the help of sensors and motors, the hand of the manipulator will make the connection. The charging station will lock the connected connector and start charging the electric car. The PDAB protection system monitors the quality of the connection;
third step: After the charging process is completed, the connector will be unlocked and the manipulator will move to the start position.

## 3. Results and Discussion

The developed system is compatible with the AutoEnterprise Charge Complex-T, and supports different types of standard charging connectors for each standard that supports the charging system. This system allows accurate positioning of the manipulator, considering the characteristics of the charging station.
During the design of the automated charging station, a module of the self-diagnostic system and protective equipment was added, which is a protection device in case of arc breakdown with a bipolar mechanism of the automatic switch. The arc breakdown detection unit monitors the current in the phase conductor with the help of two hall sensors and a voltage meter. This allows you to safely and reliably charge electric cars, which makes the process quick and easy.

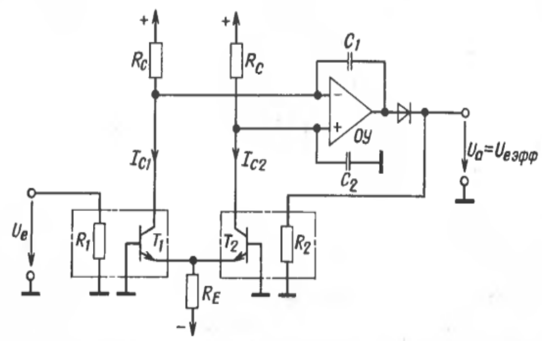

*Figure 7: Scheme of measuring the effective voltage in the circuit*

*Figure 8: Experimental design of an automated charging station*

## 4. Conclusion

The resulting design of the automated charging station is experimental and has many analogues in the world. Similarly, the modularity of the structure allows you to adapt it to other stations, and upgrade it.

The task of reducing charging time is a priority, because this is the secret of increasing the popularity of electric vehicles. In this regard, further research will be aimed at improving the control system of the manipulator for the exchange of information between the car and the charger complex, so that there is a clear connection between them.

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# Logistics Operator in the Cuban Pharmaceutical Supply Chain

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## Abstract

The current state of the pharmaceutical supply chain in Cuba demands the intervention of an operator for the global and effective management of logistic operations. Considering the structure and positioning in the supply chain, the Drug Commercialization Company has potential characteristics that favour its transformation into a logistics service provider. This paper analyses the requirements and perspectives of the company, in order to establish the theoretical basis for the development of pharmaceutical logistics in Cuba. As a result of the specialized bibliographic review, ten primary functions for a logistics operator are defined. According to the challenges presented, the preliminary results of a national wide survey identified logistics integration variables that currently affect the supply chain management. In addition, the paper presents specific strategies and research works to be implemented, in order to achieve a higher integration level through the implementation of a logistics operator in the pharmaceutical supply chain.

## 1. Introduction

Recently, the disruptions caused by the COVID-19 pandemic have demonstrated the need for coordinated and integrated logistics operations in supply chains. Pharmaceutical supply chains have had to face low inventory levels [1], long distribution times [2], government-mandated shutdowns and strict travel restrictions, affecting, above all, procurement, warehousing and distribution processes and operations. Thus, strategies and practices designed for a normal business environment have proven not to be viable [3]. Therefore, these systems have been evolving from linear processes to complex networks of organizations, resources and capabilities [4].

In this sense, logistics integration is defined as the degree to which a customer strategically collaborates with logistics operators to manage intra- and inter-organizational processes [5]. Logistics service providers have enabled the supply chain to effectively coordinate its operations among stakeholders. In recent years, the need to strengthen logistics capabilities in the Cuban pharmaceutical sector has become a prime factor. Evolution to higher levels of integration involves operational, design and relationship changes. The establishment of logistics operators in Cuba is still in the research and development phase. There are companies that fulfil many of these functions, however, they do not really operate as logistics service providers. The Drug Commercialization Company (EMCOMED) is the only one of its kind in the country and has been the main distribution, storage and commercialization centre for supplies and medicines. The transformation of this company into a logistics service provider is essential to achieve high levels of integration, but this process implies significant changes in strategy management. To this end it needs to study the company's current conditions and identify its new roles as a logistics operator in the Cuban pharmaceutical supply chain. The main goal of this paper is to analyse the current requirements and perspectives for the transformation of EMCOMED into a logistics operator.

## 2. Methods

To achieve a critical analysis on the statement of a logistics operator in the pharmaceutical supply chain, an exhaustive review of specialized literature was carried out. The keywords used for the literature review were: *"integrated supply chain management"; "logistics integration"; "logistics operators"; "logistics service providers"; and "pharmaceutical supply chain".*

A nationwide survey is applied based on five dimensions of the strategic management of a logistics operator. The managers of 30 companies out of the 48 companies currently involved in the flow of materials through primary distribution were interviewed. The survey considered the evaluation from their experience and logistics functions performed along the supply chain. The statements were evaluated according to the application level in the current supply chain management. Finally, the strategies are presented to increase the integration level among stakeholders and lay the groundwork for implementing a logistics operator in the pharmaceutical supply chain.

## 3. Results and Discussion

The definition of specific functions is a fundamental issue, since the operations performed by the logistics service provider are determined by the level of integration of the chain. To identify these primary functions, the criteria of several authors with studies published in the last 10 years were analysed. Figure 1 shows the variation in the inclusion or non-inclusion of some primary functions.

The criteria depend on the degree of specialization, level of complexity and scope of the operator in the supply chain. In general, the authors agree that the key and support processes of logistics are the most frequent. However, there is evidence of the incorporation of other functions that characterize the operations carried out by this type of company.

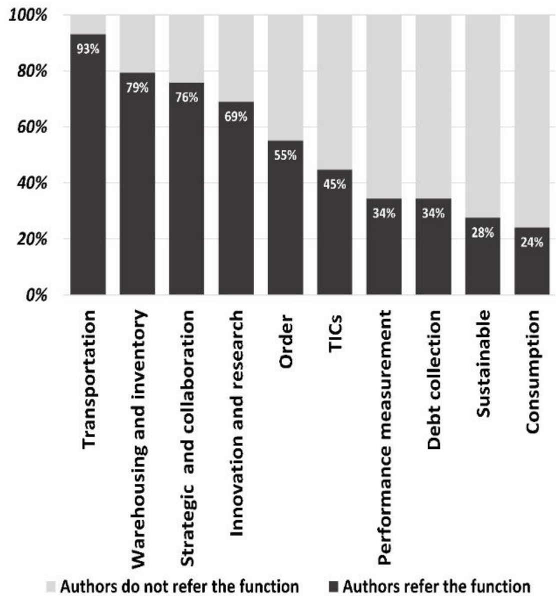


*Figure 1: Primary functions of a logistics operator according to 22 studies consulted* [4], [6], [15]–[24], [7], [25]–[28], [8]–[14]

### 3.1. Current state of the functions

#### 3.1.1. Strategic management and collaboration

A logistics operator must achieve long-term planning strategies in continuous coordination with customers. In addition, the update of the risk prevention and control manual is challenging. Concerning strategic management and the strengthening of inter-organizational relationships, the need to achieve a human resource profile that understands the scope of the company has also become evident. This requirement is one of the most immediate, since the training and development of labour competencies takes time, especially for the confrontation with new work methods and concepts.

#### 3.1.2. Order management

The order-taking and all subsequent processes are at the core of the company's internal operations. Specialists emphasize the importance of technological support for automating these operations. This is one of the processes where the logistics operator demonstrates its ability to provide real-time information with a high level of support from IT systems. Tracking orders in real-time allows the participants to manage their capacities, favouring decision-making in the face of interruption situations.

#### 3.1.3. Consumption planning

The Cuban National Medicines Program (PNM) was created in 1991 to achieve efficiency in the pharmaceutical supply chain and has been updated over the years until its most recent version in 2014.

In integrated supply chain management, demand forecasting and planning are keys activities of logistics operators. These companies, with the support of information systems and the collaboration of the participants, are responsible for capturing market consumption and coordinating successive operations for the effective satisfaction of customer needs.

Therefore, the planning of drug consumption in Cuba and the role of EMCOMED as the new manager of supply chains entails high-level modifications. Due to the high uncertainty of this type of consumption, logistics operators are responsible for providing detailed investigations of demand behaviour as a result of the use of advanced prediction tools with minimal risk.

### 3.1.4. Transportation management

According to transportation management, several authors insist that the use of optimization tools must focus on continuous improvement. This indicates that transportation management should include, from the most operational levels, the use of specialized software to maximize transportation capacities at lowest cost.

### 3.1.5. TICs management

In the particular case of EMCOMED, it has been shown that the standardization of information is a current problem, hence the integration of information systems and the use of real-time data must be a priority for the transformation into a logistics service provider. This function is also the basis for the development of all the functions of this type of company. The level of logistics integration required demands real-time information exchange for inventory management and warehousing, transportation management, drug traceability and order management.

### 3.1.6. Warehousing and inventory management

Logistics operators must be able to coordinate the material flow, eliminating excess handling or intermediate storage of loads. In this regard, the specific characteristics of the products and their form of distribution make delivery to the points of consumption difficult. These require the prior extraction of units packed in a superior unit (pinking), being a basic function for order management. This process again involves capacity and load balance studies, distribution requirements planning and a high degree of real-time exchange of stocks in each territory.

### 3.1.7. Performance measurement

To achieve effective execution of operations among participants, monitoring must be done from the base of the logistics operator to the boundaries of the supply chain itself. This is an element that favours communication, showing the result of each of their relationships and their contribution to the performance of the chain. The creation of the system requires the joint participation of both academics and specialists from the different members of the chain. Although these measurement models should focus on continuous improvement, a first proposal would help to monitor the relationships that currently exist. Business practice and the chain's own performance will demand the modification of these indicators, always in the constant search for effective control of operations.

### 3.1.8. Sustainable management

Sustainability approaches in logistics operations are becoming more frequent. Even if the specialized literature does not widely record the role of logistics service providers in environmental protection, there has been a growing interest in specifying their functions in this aspect.

Supported by the large amount of information logistics operators handle, they most collaborate in the calculation of carbon footprint and environmental impact studies throughout the material flow. They are also responsible for the final disposal of waste, a function in which EMCOMED has extensive experience.

### 3.1.9. Debt collection management

The economic and financial framework is undoubtedly one of the issues that will change the most during the transformation process. The main change lies in the company's own mission, because a logistics operator does not generate revenue by marketing products, but by providing logistics services to its customers.

First, the financial flow changes in the current structure of supply chains. The logistics operator acts as an intermediary between customers and suppliers. On the other hand, the company's finances completely change their structure and it is crucial to define the specific services to be provided and the rate for each one. Obviously, prices vary depending on the load. In relation to this factor, the supply chain presents a particularity; many of the products are large in volume and light in weight. Prior to the implementation of new operations, a detailed feasibility study is essential. The company must rely on the record of historical operations to make a balance of the activities to be carried out in the future and the benefits generated.

### 3.1.10. Innovation and research management

Finally, innovation on the implementation of logistics integration strategies is one of the main functions of a logistics operator. Although some authors do not make explicit reference to the role of this type of company in the processes of continuous improvement, all the functions explained above imply that the process of transformation of EMCOMED requires:

1. The use of scientific tools for decision support.
2. Design and implementation of integrated logistics solutions.
3. Development of a human capital profile with capabilities to provide advanced competencies from strategic to operational levels.
4. Possessing the Know-How to coordinate logistics activities with a focus on continuous improvement.
5. Systemic support of Information and Communication Technologies for the automation of information flows and real-time management.

## 3.2. Survey application

### 3.2.1. Sample selection

For the application of the survey, the 48 companies participating in the material flow of the primary chain were considered. Of these, 30 were completed, resulting in a 95% confidence level for a sampling error of 5%, so the sample is considered significant.

### 3.2.2. Evaluation criteria

For the rating, specialists and managers quantified the current level of application of the proposed statements as follows:

- 5 if it is fully applicable and there are procedures and working methods that corroborate this statement.
- 4 if it is currently applied; although this type of action is still in the development phase.
- 3 if it is partially applied; specific actions for its implementation have not yet been established.
- 2 if not applied in the company but there is knowledge about this type of actions in management.
- 1 if there is no knowledge of this type of management action.

### 3.2.3. Validation

For the validation of the survey, a reliability analysis is performed based on the calculation of Cronbach's Alpha coefficient, where the value generated must be greater than 0.7. In addition, the analysis is performed for the 5 dimensions of the survey. A Cronbach's Alpha coefficient of 0.946 was obtained for the entire survey. Table 1 shows the result for each dimension, with all values being greater than 0.7, thus demonstrating the reliability of the survey.

*Table 1: Cronbach's alpha for each dimension*

| Dimension | Cronbach's alpha |
|---|---|
| Integration among participants | 0.883 |
| Internal integration | 0.818 |
| Integration with customers | 0.804 |
| Integration with suppliers | 0.847 |
| Technology and planning integration | 0.782 |

### 3.2.4. Rating similarity

To examine the similarity of the variables and, therefore, the degree of correspondence among ratings, the deviations of the criteria for each variable in question are analysed. First, the maximum deviation that could exist between the experts' judgments according to the measurement scale is obtained. This value is calculated by deviation in the case where exactly two halves of the sample give a completely opposite evaluation. Therefore, the maximum deviation that could exist between the criteria issued by the experts is 2. Taking this deviation (lower degree of agreement as a reference), the percentage of remoteness from the deviation of each variable with respect to the maximum deviation is calculated, which makes it possible to contrast the degree of similarity of the evaluations. The results indicate that 11 of the survey variables are similarly rated, with at least 50% of remoteness from the maximum deviation. Four of these belong to the customer integration level, which means that the experts' evaluations find a high degree of similarity for this dimension. They are followed by internal integration with three variables, integration among participants and technology and planning integration with two variables each.

### 3.2.5. Coefficient of variation

To analyse the deviation of the variables with respect to a mean value, the coefficient of variation is calculated. In this case, the value of 3 on the measurement scale represents not only the mean, but the evaluation criterion that qualifies the integration approaches or variables as management elements for which no specific implementation actions have been established. Figure 2 shows the result of calculating the coefficient variation for fixed rating values. This analysis makes it possible to identify the degree of similarity between experts' judgments with respect to a specific rating. The greatest homogeneity of criteria for the logistic integration variables in the supply chain is found in the range of 3 to 5.

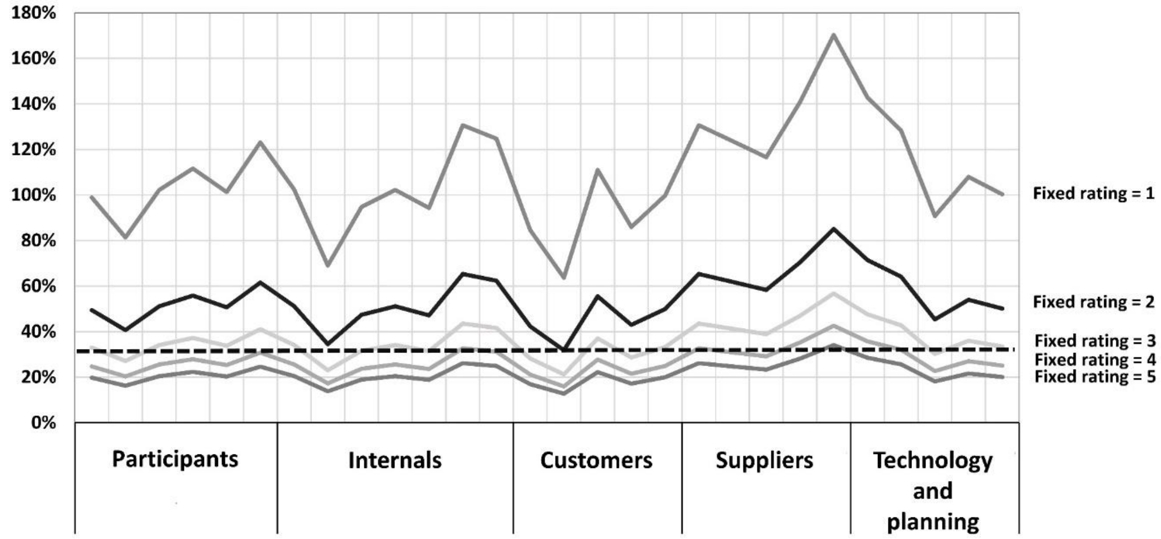


*Figure 2: Coefficient of variation for fixed values of the rating*

Considering the results, the Cuban pharmaceutical supply chain has a medium level of integration. The lower index for most of the variables indicates that specific actions for implementing logistics integration strategies have not yet been established.

### 3.3. Requirements for transformation

Following the analysis of the primary functions of a logistics operator and the current variables affecting the integration of the supply, the basic requirements to be met are detailed in Table 2.

## 4. Conclusion

The Drugs Commercialization Company in Cuba has a structure and positioning in the pharmaceutical supply chain that favours the evolution towards a higher level of coordination of logistic operations. However, managers, specialists and academics must focus on several issues that have not yet been answered in the current functioning of the supply chain.

The primary application of a nationwide survey showed a certain degree of homogeneity in the experts' criteria about the variables that currently influence the logistics integration. According to the experts' ratings, the supply chain has a medium level of integration, since most of the variables were evaluated in the range of 3 to 5. These ones are mainly affected by the absence of specific tools for the implementation of integration actions.

*Table 2: Requirements for the implementation of the logistics operator*

| **Primary functions** | **Requirements for transformation** |
|---|---|
| Strategic management and collaboration | Joint business plan design in the supply chain |
| Order management | Automated system for order management |
| Consumption planning | Implement quantitative tools for consumption forecasting |
| | Update National Drug Plan |
| Transportation management | Incorporate specialized software for transportation management |
| TICs management | Integration of information systems |
| Warehousing and inventory management | Design of a joint planning system for storage, order management, and transportation |
| Performance measurement | Design performance measurement system for the supply chain |
| Debt collection management | Upgrade financial and accounting system |
| | Define pricing rates |
| Sustainable management | Update environmental management system |
| Innovation and research management | Update research and development process |

In this sense, the paper presented specific requirements for the implementation of a logistics operator in the pharmaceutical supply chain. These future researching works must focus on the role of EMCOMED as a future logistics service provider company. However, there are certain limitations on the fulfilment of these requirements, for most of them depend on wide investments processes.

Fulfilment of these requirements depends on research projects, joint work among the participating entities and the result of an investment process along the chain, based on strengthening technological capabilities.

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# Cuban food distribution chain: Disruptions and resilience

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## Abstract:

In the current context, due to the consequences of the COVID-19 pandemic, it interrupted global supply chains by causing unprecedented shocks to supply and demand; food supply chains have been seriously affected. Food supply chains in Cuba are affected by several disruptions. Specifically, the food distribution chain of the basic food basket, which is the object of study of this paper. The objective of this research is to analyse the causes of disruptions in the supply chain. Among these disruptions, the most relevant is the uncertainty in the time of arrival of supplies for lead-time distribution and transportation disruptions. The analysis of transportation disruptions is the focus of this research. In addition, supply chains do not have a methodological procedure to manage the chain in the face of the impact of these disruptions and make it more resilient. We start with a literature review for the analysis of the concepts of disruption and resilience in the supply chain. We use the action research approach in a single case study to understand the disruptions in the food distribution chain in the basic food basket in Cuba. Then, processes are identified, KPIs are calculated and work procedures are implemented based on the analysis of previous methodologies. A procedure that analyses identifies and manages the disruptions of the distribution chain and allows the increase of resilience is the main contribution of this study. With this document, it is possible to identify disruptions in the food distribution chain and establish how to manage them to increase resilience. However, the generalization of these procedures and techniques to other companies in the country and their application requires the development of ICTs to facilitate decision-making.

## 1. Introduction

The basic food basket includes subsidized and free products that the Cuban population acquires to satisfy their minimum food and other needs. Mainly rice, sugar, beans, noodles, pasta, oil, milk, salt, fish, canned meat, coffee, cigarettes, tobacco and matches. In addition to serving people who, due to some medical condition, have a special diet because they suffer from diseases such as retroviruses, cystic fibrosis and xeroderma pigmentosum, children with low weight and height, among others, for hospitals, children's circles, nursing homes, maternity homes, homes for children without family support and sports centres [1, 2].

According to data presented by the Minister of Domestic Trade Betsy Díaz Velázquez: the basic food basket (a program that has a high priority and weekly follow-up from the territorial levels of government to the president of the country) today reaches more than 11 million registered consumers in Cuba and moves more than 100 000 tons of products monthly, which go to 13 000 retail establishments that sell the basket (warehouses) and passes from the ports to the wholesale warehouses and then to the retail network [3].

The Wholesale Enterprise of Food Products and other Consumer Goods of Villa Clara was created by Resolution No. 59 of November 4, 2002, today called Group of Wholesale Enterprises of Food Products and other Consumer Goods by Resolution No. 660/2011. It is in charge of the methodological management of 17 Basic Business Units that are grouped in a network of establishments present in the 13 municipalities of the province; counting with 23 conventional warehouses to fulfil its mission and annually circulating more than 369 thousand tons of food among them. Specifically, in Santa Clara there are three warehouses 402, 404 and 413. The last two, objects of study of this research. Each warehouse is responsible for receiving, storing and distributing certain types of products to certain destinations. For distribution, the company subcontracts the Santa Clara transport base, belonging to the Villa Clara Provincial Transportation Company (EMPA), which is in charge of transporting and distributing the products to the different stores.

Based on the cargo transport reorganization policy that began at the end of 2005 with the Operation Port-Transport-Internal Economy (OPTEI), with the support of other agencies and under the direction of MINFAR, a set of measures were adopted that transformed and strengthened the transport activity in the country; on September 29, 2008, indications were issued for the generalization of the transport reorganization in the provinces. From that moment on, the sub-directorate of loads and subordinate bases were created in each municipality of the province. The activities to be developed by the administrators of the transport bases are diverse, among them, and linked to the objectives of the research, the feedback through the OPTEI management post of the fulfilment of the transports planned for the day, especially regarding the transfer and distribution of the basic food basket. Hence, the importance of collaboration and communication among EMPA supply chain management stakeholders to avoid cargo spoilage, increased transportation costs, order delays, and order non-compliance [4].

Undoubtedly, the management of this supply chain represents a complex issue to analyse due to the large number of actors involved and the breadth of activities involved; where the distribution and transportation of products has become a high priority issue for the country in recent years. However, in the context of the new normal caused by the COVID-19 pandemic, the economy has suffered serious consequences as a result of the closure of productive activities due to the additional processes generated to contain the spread of the virus [5]. The temporary closure of factories as a result of the confinement measures, restriction of mobility to free movement and social distancing, had an impact on the labour force, as well as on freight and goods transportation services, which have been forced to reduce supply. All those companies that claimed to have a world-class distribution channel and logistics have found themselves faced with a problem that has put all their systems to the test, evidencing how transportation and distribution logistics has gained much more strength and has become a differentiating element among companies trying to increase their resilience to satisfy their customers to the maximum.

At present, the warehouses under study have been presenting problems fundamentally linked to transportation issues, an activity that depends on the vehicles sent by the Santa Clara transport base, among them: excess of operability in the transportations, which results in not achieving a stable planning, trucks used without the maximum of their capacities, extensive routes due to the little use of engineering tools in the decision making related to them, irregularity in the assignment of the loads to the vehicles, which causes deficiency in their delivery, lack of communication among the actors of the chain due to the lack of organization and control existing in the entity, noncompliance of orders in time with the client and increase of the transportation costs. All of this, together with the economic effects of the COVID-19 pandemic and an intensified economic blockade, the supply in Cuban warehouses of some of the supplies included in the regulated family food basket suffers delays due to the non-arrival on time of imported products and inputs, disruptions s in production flows and inefficiencies in the product distribution processes.

This situation, added to the current shortage conditions of several products in the country, has led many of them to be regulated for sale to the population, which is undoubtedly a particularly sensitive issue. Even in recent months, the distribution and delivery to the population of coffee and cigarettes, products of very high demand, has been strongly affected by the elements previously mentioned [6]. There are two main disruptions that encompass these problems, depending on the link in the supply chain: products not being in the warehouse in time for distribution (supply disruption) and transportation problems due to lack of collaboration between the actors in the chain (transportation disruptions) [7]. For this reason, the objective of the study is to establish a working methodology to manage transportation disruptions and improve resilience in the distribution chain. This document is structured in four sections. The next section describes the procedure and the tools to be used. The third section proposes the analysis of the tools used with the support of monitoring and control indicators. Finally, conclusions, limitations and future research are proposed.

## 2. Proposed methodology

The document is divided into four main stages, as shown in Figure 1:

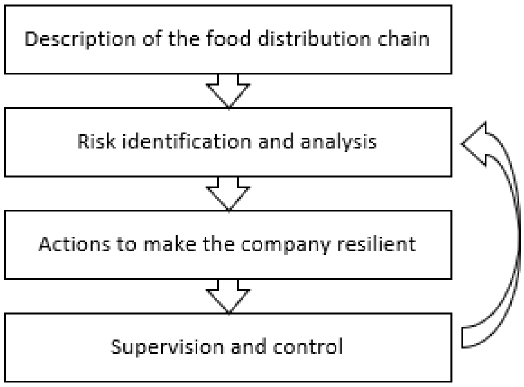


*Figure 1: Proposed Methodology*

The selected process is described, taking into account the General Guide for the Characterization of Potential Supply Chains [8]. The main transportation policies applied in the country are summarized and a SWOT matrix is established for each of the actors involved in the transportation of products [9, 10]. The second step is to determine the risks and/or disruptions in the chain with the support of risk estimation tools [11-14].
Next, a set of measures is proposed to increase the chain's resilience to transport disruptions [15]. Mainly the redesign of all distribution routes in the 12 zones into which Santa Clara's warehouses are divided. Finally, the monitoring and control of the means of transport used with the proposed integration indicators is proposed [16]. Here there is a feedback with the identification and analysis of risks.

## 3. Results and Discussion

### 3.1. Description of the food distribution chain

In order to diagnose the supply chain under study, the products for the end customer were first identified. Warehouse 404 is responsible for the distribution of rice, grains, sugar, salt, oils and fats. Warehouse 413 distributes canned food, pasta, coffee, cigarettes, tobacco, matches and noodles. In the correct functioning of the chain, it can be seen that there is a strong commitment by the government that every first day of the month the products of the regulated family basket must be in the warehouses and that each link in this chain complies with its plan. However, there is no integrated planning between the management of the entities involved and all planning is done in individual cases. This is due to the fact that the supply chain does not have a coordinating entity because each member has different interests and responds to different organizations. Work should be done on training, on the link between scientific organizations, managers and specialists of the member entities and, above all, emphasis should be placed on the use of engineering tools for decision making as to what and how to transport.
For the analysis of the chain's problems, each of the problems that hinder the fulfilment of the chain's main objective and their causes, which were identified through a brainstorming session with the experts, are evaluated, considering the causes that lead-time non-compliance.
Tables 1 show the current problems of each link as well as the strategy to be applied.

*Table 1: Strategies for each chain link*

| | Current problems | Strategies |
|---|---|---|
| **Supplier** | Delivery of poor-quality products.<br>Delays at the port.<br>Delays in lead- times. | Expand new suppliers. |
| **EMPA** | No use of the capacity of the vehicles in the loading process.<br>Little informatization of the processes. | Implement procedures that contribute to improve transportation management.<br>Plan activities that contribute to the informatization of processes. |
| **Transport base** | Delays in lead time due to the capacity of the trucks and the non-existence of the optimum pre-established route.<br>Impunctuality of the drivers on arrival at the warehouses for the dispatch of merchandise. | Improve transportation management.<br>Obtain new distribution routes.<br>Implement corrective measures for workers. |
| **Client (stores)** | Storage capacity and conditions. | Conduct a study of the conditions for the storage of products in the stores |

In the last years, the transport policy has changed, especially since the COVID-19 pandemic. The movement of basic commodities has been

*Table 2: Transportation disruptions*

| Failure mode | Effect | Causes | RL |
|---|---|---|---|
| Storing incorrect information | Insufficient control of efficiency indicators. | Information and control system. | H |
| Technical equipment failures | Accidents and impossibility to use the equipment. | Lack of maintenance. | H |
| Lack of transport planning | Incorrect use of resources. | Little innovation and lack of knowledge and tools. | H |
| Truck replacement | Compatibility of loads. Use of static and dynamic capacity. | Breaking and maintenance | H |
| Raw material to transport | Transportation is not provided. | Supply disruptions | S |
| Closed roads | Creation of new distribution routes or transportation traffic backlogs | Flood, events and repairs | S |
| Roads poorly paved | Wear and tear of the vehicles. | Road wear and tear | S |
| Driver replacement | Lack of knowledge of the stores and work procedures in each zone. | Fluctuation in employment | S |
| Lack of equipment maintenance | Accidents and impossibility to use the equipment. | Lack of tools | S |
| Late arrival at goods dispatch | Delayed transportation and failure to take advantage of the job labor time. | Job Indiscipline | S |
| Damage to the goods. | Missing distributions. | Natural events, human negligence | S |
| Traffic accident | Failure to complete the objective, loss of cargo or human lives. | Negligence of the driver, technical failures of the equipment and outside | S |
| Traffic violations | Fines and merchandise delay. | Driver's negligence | S |
| Crime and merchandise theft | Delays in orders and product shortages. | Staff negligence, abuse of power, and other external | S |

*Legend: RL (risk level), H (high), S (Significant)*

rationalized and prioritized and the documentation required for their control has been established. This documentation [17] is included in the balance sheet, which includes the following steps:

- Updating of the inventory of freight transport means and calculation of transport capacity, according to BC-1 and BC-2 models.
- Determination of the transport demand, according to Model BC-2.
- Preparation of the transport plan, according to models BC-3, BC-4 and BC-5.

At the Santa Clara transport base, the components for the elaboration of the SWOT matrix were identified through direct observation, document analysis and the exchange with managers and workers of the base. It can be seen that taking advantage of the cargo base's opportunities is fundamental to better manifest its strengths and reduce its weaknesses to a minimum. To prepare the SWOT matrix for UEB 413, we proceeded in a similar way as we did with the transport base. Thus, the ideal strategy for the warehouse is to make the most of the strengths to neutralize the threats and benefit from the opportunities.

## 3.2. Risk identification and analysis

Once it has been established that one of the fundamental disruptions are those related to transportation, the failure modes, causes and their effect on the institution are determined. In addition, the consequence, the probability of occurrence and the level of risk are estimated. The table 2 shows the risks that are classified as high and significant for the food distribution chain.

## 3.3. Actions to make the company resilient

Due to the importance of transportation and the risks involved, it was decided to determine the optimal routes from each warehouse to the warehouses. For this purpose, a map was created using Google Maps and ArcGIS to determine the distance matrix of the warehouses in each of the zones into which the municipality of Santa Clara is divided. Then with the use of the traveling agent method programming [18], the best food distribution routes for each of the 12 zones are determined.

Example of a work system proposal for the distribution of coffee and cigar products due to the high consumption of the population and the scarcity of their production due to the impact of Covid 19. The same is done considering the zones established by the warehouse for the distribution of coffee and cigars (and the rest of the products of the UEB), zone 4 Camajuaní Urban-Rural is chosen (for being one of the longest distances covered in its routes). The route is composed of 12 stores whose demand for coffee is one pack per family member and for cigars is 5 packs per nucleus.

Determining that the best sequence obtained, which minimizes the distances between nodes by visiting them only once and returning to the starting point, is: Warehouse 413 - Río Plata - La Ideal - El Acuario - La Victoria - El Arroyo - La Armonía - El Bélico - Viñales - El Camino - La Vereda - Comercial Capiro - La Bonita - Warehouse 413, with a total distance of 13.65 km.

Based on this information and the values of loading and unloading times, it is possible to determine the travel time and the vehicles needed. This information is useful for the load balancing of the warehouse and the transport base, allowing them to plan the demand and the transportation plan according to the BC-2, BC-3, BC-4 and BC-5 models.

### 3.4. Supervision and control

Once the analyses have been carried out, a set of indicators are proposed for the control of disruptions among the supply chain actors analyzed. The indicators shown in Table 3 (A and B) are divided into two groups. They depend on the characteristics and information requirements of the company they represent. These indicators should be evaluated on a monthly.

Table 3A: Indicators for transport base

| **Transport base** | |
|---|---|
| Existing equipment | Units |
| Equipment at work | Units |
| Average static capacity | T |
| Cargo to transport | T |
| Number of trips to be realized | Units |
| Possible load | T |
| Fixed-term certificate of deposit (CDT) | % |
| Customer Acquisition Cost (CAC) | % |
| Rotation of vehicles | Units |
| Distance to be traveled | Km |
| Load distance | Km |
| fuel consumption | L |
| Traffic | t – Km |
| Average distance from 1t | Km |
| Consumer index | Km / L |
| Diesel - Traffic Index | L / t – Km |
| Revenues | CUP |

*Table 3B: Indicators for food company*

| **The Wholesale Enterprise of Food Products and other Consumer Goods of Villa Clara** | |
|---|---|
| Warehouse cost per m$^2$ | $ |
| Delivery cost | $ |
| Transportation cost per truck | $ |
| Transportation cost per unit delivered | $ |
| Warehouse inventory | Units |
| Inventory rotation | Units |
| Orders delivered on time | Units |
| Orders delivered complete | Units |
| Percentage of merchandise wastage | % |
| Average number of times the same product is taken to the same store | Units |
| Use per trip of the static and volumetric capacities of the vehicle | Units |
| Time required to transport the basic basket to all store | days |
| Use of working time | % |
| Average number of trips to each store | % |
| Relationship between the type of cargo to be moved and the truck transporting it | Yes/ No |

## 4. Conclusion

The policies adopted by Cuba in recent years are aimed at centralizing transportation and use of more efficient schemes and means for this activity, through the improvement of the cargo balance and the MITRANS directives. The integration of the Santa Clara transportation base with the Wholesale Food Company, as actors involved in the supply chain of the distribution of basic food basket products, is fundamental to achieve the optimization of the resources involved in the process. The application of tools such as the general guide for the characterization of potential supply chains, the SWOT matrix, risk estimation tools, the redesign of routes with the traveling agent and the creation of indicators made it possible to understand the current characteristics of the chain and enhance resilience to transportation disruptions. The results obtained are very useful for transportation planning through load balancing, efficient use of resources, transportation management at different hierarchical levels and the evaluation of performance indicators at each level, all of which contribute to increasing the level of customer service in the supply chain under study. However, the generalization of these procedures and techniques to other companies in the country and their application requires the development of ICTs to facilitate decision-making.

For future research, it is proposed to continue with the study of disruption due to supply shortages, another of the main disruptions s in the chain. In addition to the potential resilience of the institutions based on a strategy of collaborative work among the chain's actors.

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# Optimization Model for Berth and Transshipment Scheduling

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## Abstract

Several research works have focused on Berth Allocation Problem (BAP) with the consideration of transshipment of ship-to-ship. However, to the most of our knowledge, there are no studies, that decide whether direct transshipment service should be made according to vessel's berthing time in the continuous (BAP) variant where vessels can berth anywhere alongside quays. To fill this gap, this study introduces the continuous (BAP) and formulates a novel mathematical model, which deals with the question of direct transshipment. The aim is to minimize the dwell times and the penalty accrued by tardy vessels [1]. Firstly, a mixed integer linear program is implemented to schedule incoming vessels to berthing positions and decide the transshipment method needed for each couple of vessels. Secondly, a genetic algorithm is proposed to solve large-scale problem instances. Numerical experiments were conducted, and the results are analysed and compared on a set of randomly generated instances. The designed solution approach provides near optimal solutions for comparable real size problems in a reasonable amount of time.

## 1. Introduction:

Optimizations of berth allocation and transshipment activities have received so far, a larger attention in the scientific literature in the last few years (Zhen et al. 2011 [2], 2016 [3]; Lee and Jin 2012 [4]; Tao and Lee 2015 [5], Schepler et al. 2017 [6]). [2] integrate both the berth allocation problem and container storage space allocation problem (SSAP) including the assignment of quay cranes at the tactical level in transshipment hubs. [3] focused on the terminal assignment problem considering fuel consumption, ITT, and storage cost. [4] schedule template for feeder vessels to reduce workload congestion in transshipment terminals. A memetic heuristic was developed to solve large instances. [5] studied the berth and yard allocation problem for transshipment hubs to minimize the total distance of exchanging containers between mother vessels and feeders. [6] used restrict-and-fixed heuristics to solve terminal allocation problem (TAP) for multi-terminal systems and minimize weighted turnaround times. In the literature, although there are many papers that applied continuous berth layout approach (Ganji et al. 2010 [7]; Lee et al. 2010[8]; Park and Kim 2002[9]), few of them consider a berth allocation problem with direct transshipment consideration. In their model, Liang et al. (2012) [10] assumed that the direct transshipment is only used between two vessels berthed at the same berth. However, they raised additional requirements for the berthing positions of the involved vessels and the operations of the QCs. They proposed a Genetic Algorithm (GA) and the solution of an example instance confirmed that direct transshipment can accelerate the service process. [9] studied a BAPC with an objective that minimizes the costs of delayed departures of ships due to the undesirable service order and those of additional complexity in handling containers when ships are served at non-optimal mooring locations in port. Their work is more practical than the aforementioned BAPC research works in that the factors assessed in the objective depend on the quay locations of ships. [7] proposed a GA-based heuristic which found near optimal solutions for small-sized instances with 3 vessels and was able

to solve larger instances with 30 vessels in 6 min. In [8] two greedy randomized adaptive search procedures (GRASP) are developed for the BAPC. Finally, in [11], a bi-objective optimization integration model of tactical and operational planning in container terminal operations is presented. It consists of tactical berth allocation problem, specific quay crane assignment problem, tactical yard allocation planning and quay crane scheduling problem.
In this paper, a novel mono-objective integration model is proposed to deal with the continuous variant of BAP and the direct and indirect transshipment tasks. We extend the relative position formulation of [1]. An exact method and an adapted (GA) are proposed to solve the problem. In our model, the transshipment consideration is similar to [10], however the authors dealt with a discrete variant and used a different modelling strategy.

## 2. Model and resolution approach

In this section, we present a mixed linear programming formulation to solve the berth allocation problem with the consideration of transshipment of ship-to-ship. Before that, we introduce some terminology and sets, which will be used in all the formulation later.

### 2.1. Problem Description

Arriving at the terminal, a ship must fulfil several tasks. Generally, part of its goods must be transferred directly to another ship, another part must be stored temporarily in the terminal yard while the rest of the cargo can be unloaded and stored without transshipment. The proposed mathematical model extends the research done by [1]. We assume quay is partitioned into a determined number $B$ of equal sized docks. Each position can be occupied by at most one ship at a time. In addition, since the number of containers carried by a mega-ship is high, the processing time required to process such a ship may exceed one day. Therefore, we choose to discretize time using relatively long periods of 3 or 4 hours. We are interested in a set of ships whose arrival dates are known in advance, with $V = M \cup F$ where M and F represent respectively all mother and feeder ships. For each ship $i \in V$, We define: $l_i$ length of the ship i, $p_i$: processing time of the ship i, $a_i$ : arrival date of vessel i and $d_i$: estimated departure date of vessel i. Given the information vector $\{l_i , p_i, a_i , d_i\}$ of a ship i arriving at the terminal, the optimization problem then consists of to determine the berthing position $b_i$ of this vessel ($1 \leq b_i \leq B-1$) where B is the set of berths), the date of berthing $t_i$, develop the duty order sequence and assign the start time of each handling operation for each vessel i. The problem is suitable under the following assumptions:

- The vessel must be serviced without disruption from its arrival at the terminal until its departure.
- Container transshipment operations between ships only exist between mother ships and "feeder" ships and they can be carried out between several ships at the same time. Thus, mother ships can trade containers with up to six "feeder" ships, while "feeder" ships can be assigned to up to three mother ships.
- Incoming ships can dock at the quay without any physical restrictions.

The sets, parameters and decision variables used to build the two models are as follows:
$c_i$: the earliest time that vessel i can depart
$d_i$: due time of vessel i (where $d_i \leq t_i + p_i$).
$f_i$: lateness penalty of vessel i.
$h_i$: length of vessel i measured in number of required berth sections.

$$w_{ij} \begin{cases} 1 & \text{if there is a transshipment operation between vessel i and vessel j} \\ 0 & \text{otherwise} \end{cases}$$

$$x_{ij} \begin{cases} 1 & \text{if vessel j berths after vessel i departs} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ij} \begin{cases} 1 & \text{if vessel j berths completely above vessel i on the time} - \text{space diagram} \\ 0 & \text{otherwise} \end{cases}$$

$$D_{ij} \begin{cases} 1 & \text{if there is a direct transshipment between vessel i and vessel j} \\ 0 & \text{otherwise} \end{cases}$$

$$I_{ij} \begin{cases} 1 & \text{if there is an indirect transshipment between vessel i and vessel j} \\ 0 & \text{otherwise} \end{cases}$$

## 2.2. Mixed integer linear formulation

Min f =
$\sum_{i \in F \cup M}(c_i - a_i) + \sum_{i \in F \cup M} f_i.(c_i - d_i)^+$ (1)

$x_{ij} + x_{ji} + y_{ij} + y_{ji} \geq 1 \; \forall \; i, j \in F \cup M \; i < j$ (2)
$x_{ij} + x_{ji} \leq 1 \quad \forall \; i, j \in F \cup M \; \; i < j$ (3)
$y_{ij} + y_{ji} \leq 1 \quad \forall \; i, j \in F \cup M \; \; i < j$ (4)
$t_j \geq c_i + (x_{ij} - 1).M \; \; \forall \; i, j \in F \cup M \; i \neq j$ (5)
$b_j \geq b_i + h_i + (y_{ij} - 1).M \; \; \forall \; i, j \in F \cup M \; \; i \neq j$ (6)
$t_i \geq a_i \qquad \forall \; i \in F \cup M$ (7)
$c_i \geq t_i + p_i \qquad \forall \; i \in F \cup M$ (8)
$b_i \leq B - (h_i + 1) \qquad \forall \; i \in F \cup M$ (9)
$b_i \geq 1 \qquad \forall \; i \in F \cup M$ (10)
$D_{ij} + I_{ij} = 1 \; \forall \; i \; \forall \; j \in F \cup M \; w_{ij} = 1, \; i \neq j$ (11)
$| \; t_i - t_j \; | \geq I_{ij} \; \; \forall \; i \; \forall \; j \in F \cup M \; w_{ij} = 1 \; \; i \neq j$ (12)
$| \; t_i - t_j \; | \leq I_{ij}.M \; \forall \; i \; \forall \; j \in F \cup M \; w_{ij} = 1 \; i \neq j$ (13)
$x_{ij}, y_{ij}, D_{ij}, I_{ij} \in \{0, 1\} \; \forall \; i \; \forall \; j \in F \cup M \; i \neq j$ (14)

Constraints (2)-(4) ensure that no vessel rectangles overlap. Constraints (5) and (6) ensure that the selected berthing times and berthing positions are consistent with the definitions of $x_{ij}$ and $y_{ij}$, where $M$ is a large positive scalar. Constraint (7) and (8) force berthing time to occur no earlier than arrival time, and departure time to occur no earlier than service completion time. Constraints (9) and (10) guarantee that all vessels fit on the berth. Constraint (11) ensures that a couple of incoming vessels must work with only one handling operation including non-transshipment or transshipment containers. Constraints (12) and (13) ensure that only the couple of vessels arriving at the same time should have a direct transshipment.

## 2.3. Genetic algorithm

Our BAP variant is clearly NP-hard [1]; To validate the model we used CPLEX to find optimal solutions for small instances. To solve large size instances, we adapted a Genetic Algorithm (GA) by combining it with techniques based on the 2D collision detection problem to select feasible solutions. We choose the GA approach since our problem structure is suitable for this metaheuristic, therefore its implementation is much easier. The first decision to make while implementing a GA is to properly define each individual. This step associates to each point of the search space a specific data structure, called chromosome. It has been observed that improper representation of solutions, having an improper definition of the mappings between the phenotype and genotype can lead to poor performance of the GA. In this problem, each solution is represented by a artificial chromosome (row) composed of a set of genes indicating the coordinates of each ship on a time-space diagram as well as their transshipment relationships. A binary representation is used for the binary variables $x_{ij}, y_{ij}, D_{ij}$ and $I_{ij}$ where the genotype consists of a bit strings of $4 \times (N_1 + N_2)^2$ elements, where the $k^{th}$ element indicates whether the decision $k$ is chosen (=1) or not (=0). For continuous variables (namely $b_i$, $t_i$ and$c_i$), the genes are defined using a real valued representation of $3 \times (N_1 + N_2)$ elements. In Fig 1, we illustrate an explanatory example of the proposed coding. Such a representation offers certain facilities. Indeed, the genotype becomes structured and can be broken down into different identifiable parts, thus allowing its exploitation by crossbreeding and mutation operators.

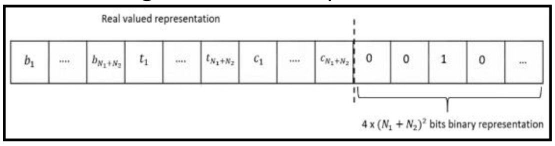


*Figure 1: Representation of an individual's chromosome (genotype).*

In our algorithm, the population is defined as a two-dimensional array of – size population, having two main properties: the position in the search space and the cost. The diversity of the population should be maintained otherwise it might lead to premature convergence. For this purpose, we populate the initial population with completely random solutions. We note that the population size was decided by trial. GA strongly depends on the step of selecting parents. However, when the problem has several constraints, it becomes difficult to find a randomly feasible solution. For this reason, we have designed technique based on the 2D collision detection problem [12] to select feasible parents. A feasible solution of the BAP is called a berth schedule x. Any such x can be depicted on a time-space diagram where the horizontal axis measures time and the vertical axis represents berth sections [1]; see Fig 2. A vessel i is modeled by a rectangle whose length is its processing time $p_i$ and height is its length $h_i$. To determine berthing section $b_i$ and berthing time period $t_i$ for each vessel i, we select pairs of known solutions as parents from the current population and we ensure there is no gap between any of the 4 sides of the rectangles. Any gap means a collision does not exist

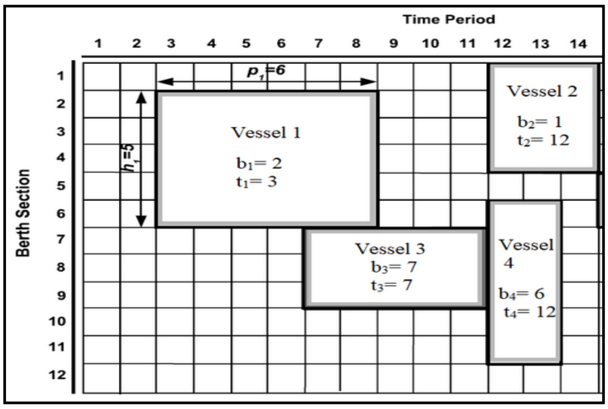


*Figure 2: Representation of a berth schedule on a time-space diagram. Figure taken from [1] and readjusted.*

#### 2.3.1. Crossover operators

In the proposed problem, the resulting vessel and container transshipment scheduling plans may not be feasible if the crossover operator is not properly designed. In our model, two main types of variables are used: the binary and the continuous variables. For each type different crossover operators have been used to deal with the proposed problem. For the binary variables one of these 3 operators is randomly chosen:

- Single- Point Crossover: a random crossover point is selected and the tails of the two parents are swapped to get new off-springs.
- Double- Point Crossover: 2 random crossover points are selected, and the middle segments are swapped to get new off-springs.
- Uniform Crossover: treats each gene separately and decides which genes are inherited from the first parent, and which one are inherited from the second parent.

Let
$x_1 = (x_{11}, x_{12}, x_{13}, \ldots, x_{1n})$ and
$x_2 = (x_{21}, x_{22}, x_{23}, \ldots, x_{2n})$
be two parents and
$y_1 = (y_{11}, y_{12}, y_{13}, \ldots, y_{1n})$ and
$y_2 = (y_{21}, y_{22}, y_{23}, \ldots, y_{2n})$be the two offsprings of this crossover. We use the following formulae
$y_{1i} = \alpha_i . x_{1i} + (1 - \alpha_i). x_{2i}$
$y_{2i} = (1 - \alpha_i). x_{1i} + \alpha_i . x_{2i}$
Where
$\alpha = (\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_n)$ & $\alpha_i \in \{0, 1\}$.
The crossover process practiced in GA for the continuous variables is similar to the binary uniform crossover process. Let
$x_1 = (x_{11}, x_{12}, x_{13}, \ldots, x_{1n})$ and
$x_2 = (x_{21}, x_{22}, x_{23}, \ldots, x_{2n})$ be two parents and
$y_1 = (y_{11}, y_{12}, y_{13}, \ldots, y_{1n})$ and
$y_2 = (y_{21}, y_{22}, y_{23}, \ldots, y_{2n})$be the two offspringsobtained in this crossover operation. This works by taking a set $\beta = (\beta_1, \beta_2, \beta_3, \ldots, \beta_n)$ where $\alpha_i \in \{0, 1\}$ and by using the following formulae
$y_{1i} = \alpha_i . x_{1i} + (1 - \alpha_i). x_{2i}$
$y_{2i} = \alpha_i . x_{2i} + (1 - \alpha_i). x_{1i}$

#### 2.3.2. Individual Feasibility Check

The crossover operation may result in solutions or chromosomes that are not feasible. It is therefore necessary to check and correct them. The basic verification rules are:

- no vessel rectangles overlap.
- all vessels fit on the berth.

Thereby, we propose 2D collision detection algorithm [12].

#### 2.3.3. Mutation operators

A reproduction using only the crossover operator can be trapped in local optima. The genes of the children are limited by the genes of the parents, and if a gene is not present in the initial population (or if it disappears due to reproductions), it can never develop in the descendants. It consists of modify one or more genes of an individual selected by the selection operator. In this problem, we propose two mutation strategies for each kind of variables:

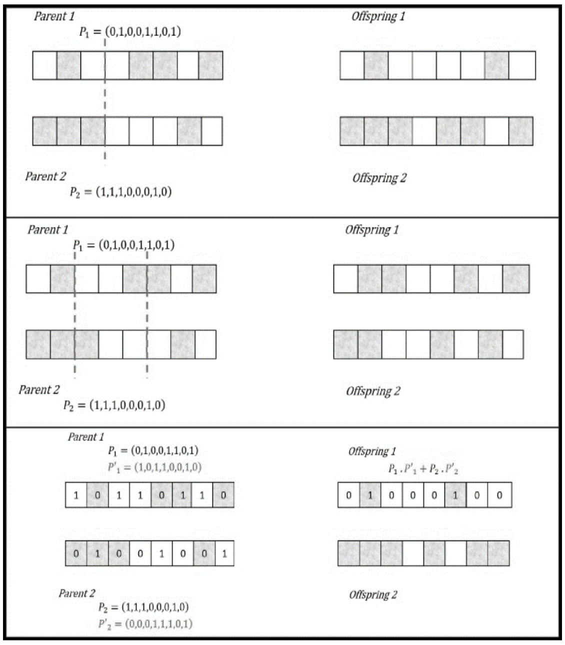


*Figure 3: The figure show (from top to bottom) the single point crossover, the double point crossover and the uniform crossover process.*

#### 2.3.4. Mutation M1 (for binary variables)

Given the chromosome $x = (x_1, \ldots, x_n)$. A random gene $x_i$ ($\in \{0,1\}$) is selected from $x$ , and a uniform random value is assigned to it. Let j be a random integer index ∈ $\{1, \ldots, n\}$. Mutation is carried out by

$$x_i' = \begin{cases} x_i & \text{if } i \neq j \quad i = 1, \ldots, n \\ 1 - x_i & \text{if } i = j \end{cases}$$

### 2.3.5. Mutation M2 (for continuous variables)

Given the chromosome $x = (x_1, \ldots, x_n)$. A random gene $x_i$ ($\in \{0,1\}$) is selected from $x$. Let $j$ be a random integer index ∈ $\{1, \ldots, n\}$. The main mechanism of M2 consists of changing value by adding random noise drawn from normal distribution. M2 requires two parameters: the mean $\xi$ and the standard deviation $\sigma$. Mutations then are realised by adding some $\Delta xi$ to each $xi$, where the $\Delta xi$ values are randomly drawn using the given $N(0, \sigma^2)$ distribution, with the corresponding probability density function.

$x_i' = x_i + N(0, \sigma^2)$

The mean of $\Delta xi$ is equal to zero and the standard deviation is equal to $\sigma^2$ which represents the mutation step size.

## 3. Results and Discussion

To test the quality and performance of the GA and the proposed model, we consider two types of instances. The first type consists of a set of instances small random numbers that can be solved exactly by the optimization software CPLEX. Small instances are considered in this chapter to compare the results obtained by the GA method with those provided by CPLEX. The second type is based on a set of medium and large size randomly generated.

### 3.1. Experimental environment and setting parameters

The used approaches for the resolution of the small instances of this problem have been implemented with Java using NetBeans IDE 8.2. For large scale instances, GA has been implemented using MATLAB. By default, all experiments were conducted on a Intel® Core ™ i5-4570 CPU @ 3.20 GHz, RAM 4 GB. The final adjustment of the parameters of the proposed algorithm is shown in Table 1. The values presented in this chart are the result of several intensive studies we conducted to refine the GA. We note that the population size is set alternately at 25, 50, 100 and 150, which is an appropriate size for decision-makers to exchange solutions among the population. In our preliminary experiments, we tried to tune different combinations of probability of crossing (pc) and probability of mutation (pm) on a set of instances, while keeping the other parameters. For each instance and each combination, 20 independent analyses were performed. We can confirm that the effects of the mutation probability show that a small (pm) is likely to improve the values of the solutions obtained when (pc) is large. Therefore, we set pc= 0.9 and pm = 0.05 as final parameters.

*Table 1: Parametric configuration of GA*

| Parameter description | Values |
|---|---|
| Population size (nPop) | $\in \{25,50,100,150\}$ |
| Crossover Percentage (pc) | 0.9 |
| Extra Range Factor for Crossover (gamma) | 0.4 |
| Mutation Percentage (pm) | 0.05 |
| Mutation Rate 1 (mu) | 0.05 |
| Mutation Rate 2 (mub) | |
| Maximum Number of Iterations | 0.02 |
| | 200 |

### 3.2. Instance generation

First, we report, in Table 3 (in Appendix), the parameters relating to the set of vessels V considered in this work. For each instance "DG" indicated in the first column, a number N of mixed-size vessels must be transported (N = N1 + N2, where N1 indicates the number of mother vessels and N2 the number of feeder vessels). The set of berths B, N1 and N2 are displayed in the second column. The third column indicates the values of $a_i$,$d_i$, $f_i$,$h_i$,$p_i$. The transshipment ship pairs in each instance are reported in the last column. Six sets of test problems were used, each containing 4 different generated instances. The first three of these sets include relatively small problems for a terminal with B = 12, and N = 10; 12; and 14 vessels respectively. The next three problem sets contain larger instances with B = 20 and with N = 20; 25; and 30 vessels. The same ranges of parameter values from [1] are used to control the generation of independent random parameter sets in the computational experiments (Table 2).

*Table 2: Ranges of parameters used in the computational experiments*

| Parameters | Intervals | |
|---|---|---|
| $h_i$ | [2,6] | |
| $p_i$ | [1,4] if $h_i = 2$<br>[1,5] if $h_i \in \{3,4\}$<br>[1,6] if $h_i \in \{5,6\}$ | |
| $a_i$ | [1,10] for small instances | [1,20] for large instances |
| $d_i$ | $a_i + K.p_i$ | where $K \in$ [1,3] |
| $f_i$ | [3,5] | |

### 3.3. Results

According to Table 4, we can confirm the validity of our mathematical model proposed for all the small instances studied. In fact, the values obtained by minimizing $f$ have reached the theoretical lower bound. We observe that CPLEX has enabled to optimize the majority of the cases of the small instances studied in a few seconds. Table 6 contains the identifier of the instances studied "Inst", the columns "CPLEX" & "GA" represent, respectively, the results obtained by the exact method and the meta-heuristic applied on the instances of Table 5.. The values under the heading "Obj Val" indicate the best solution found by these two methods. The CPU corresponding to the execution of each instance in seconds is reported in the "CPU(s)" columns. The values under the "Dev" header indicate the deviation of CPLEX and GA results from the best solution. The value of the corresponding objective function indicated in the "Obj Val" represents the optimal solution, or the best bound found within 3600 seconds. The results in Table 6 confirm the performance of the GA adapted to the proposed model. They clearly show the effectiveness of this approach in relation to small instances size, thus offering optimal solutions.

## 4. Conclusion and future work

This paper deals with a new mathematical model for the integration, of the Berth Allocation Problem (BAP) and the container transshipment problem. A mixed integer linear program is implemented in Netbeans (using Java language and CPLEX library) to schedule incoming feeders and mother vessels along the terminal quay to berthing sections and decide the best transshipment method to use (direct/indirect) for each couple of vessels. A MATLAB implementation of a genetic algorithm is also proposed to solve large-scale problem instances. Numerical experiments were accrued on a set of randomly generated instances. The numerical results are analyzed and compared. The designed solution approaches provides optimal solutions for small and medium size problems in a reasonable amount of time. Encouraging results have been obtained. There is still more work to be done: an application of the proposed genetic algorithm on large size instances of this problem must also be provided. An analytical comparison between the single point, double point and the uniform crossover will be encountered in the future as well. Finally, we intend to extend the model by considering multiple objectives. It would be worthwhile to integrate another decision problem such as the Yard Allocation Problem (YAP) or the Quay Crane Assignment Problem (QCAP) and to use other resolution strategies and metaheuristic approaches.

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[12] https://developer.mozilla.org/en-US/docs/Games/Techniques/2D_collision_detection

## *Appendix*

*Table 3: Description of small sized instances*

| Instance name & no | (N1- N2-B) | Parameters values | Transshipment vessels pairs |
|---|---|---|---|
| **DG1** | (4-6-12) | $a_i = [1, 1, 1, 7, 7, 10, 10, 8, 10, 8]$<br>$h_i = [2,6,3,4,4,5,6,3,3,2]$<br>$p_i = [3,6,4,3,3,5,3,5,5,3]$<br>$f_i = [3,5,3,4,4,4,5,3,3,3]$<br>$d_i = [7,13,13,10,10,15, 16, 18, 20,14]$ | (1,2) , (1,3) , (2,3) , (4,5) , (6,9) |
| **DG2** | (4-6-12) | $a_i = [1, 3, 2, 1, 7, 10, 7, 7, 10, 10]$<br>$h_i = [3,4,2,2,4,6,5,4,4,5]$<br>$p_i = [5,5,3,4,5,4,6,5,2,4]$<br>$f_i = [5,5,3,4,4,5,5,5,3,4]$<br>$d_i = [6855,12,14,13,12,12,14]$ | (1,3) , (7,8) |
| **DG3** | (4-6-12) | $a_i = [1,1,3,1,3,5,7,10,10,10]$<br>$h_i = [2,3,4,6,6,6,5,6,2,5]$<br>$p_i = [3,2,4,2,2,5,5,6,2,6]$<br>$f_i = [3,3,3,3,3,4,4,5,3,5]$<br>$d_i = [4,3,7,3,5,10,12,16,12,16]$ | (1,2) |
| **DG4** | (4-6-12) | $a_i = [1,2,4,1,1,4,6,9,9,8]$<br>$h_i = [2,2,2,5,2,6,4,5,3,3]$<br>$p_i = [2,2,2,3,3,4,3,3,3,2]$<br>$f_i = [3,3,3,4,3,5,4,5,3,4]$<br>$d_i = [7,4,6,4,7,8,9,15,12,10]$ | (1,2) , (1,3) , (1,5) , (2,3) , (2,4) , (3,6) , (3,7) , (4,5) , (4,6) , (5,6) , (6,8) , (6,10) , (7,9) , (8,9) |
| **DG5** | (4-8-12) | $a_i = [1,1,1,7,7,10,10,8,10,8,5,5]$<br>$h_i = [2,6,3,4,4,5,6,3,3,2,4,5]$<br>$p_i = [3,6,4,3,3,5,3,5,5,3,5,6]$<br>$f_i = [3,5,3,4,4,4,5,3,3,3,4,5]$<br>$d_i = [7,13,13,10,10,15,16,18,20,14,10,11]$ | (1,2) , (1,3) , (1,11) , (1,12) , (2,3) , (4,5), (6,9) , (12,6) , (8,1) , (9,1) |
| **DG6** | (4-8-12) | $a_i = [1,3,2,1,7,10,7,7,10,10,5,5]$<br>$h_i = [3,4,2,2,4,6,5,4,4,5,4,5]$<br>$p_i = [5,5,3,4,5,4,6,5,2,4,5,6]$<br>$f_i = [5,5,3,4,4,5,5,5,3,4,4,5]$<br>$d_i = [6,8,5,5,12,14,13,12,12,14,10,11]$ | (1,2) , (1,3) , (1,11) , (1,12) , (2,3) , (4,5), (6,9) , (12,6) , (8,1) , (9,1) |
| **DG7** | (4-8-12) | $a_i = [1,1,3,1,3,5,7,10,10,10,3,7]$<br>$h_i = [2,3,4,6,6,6,5,6,2,5,6,5]$<br>$p_i = [3,2,4,2,2,5,5,6,2,6,4,3]$<br>$f_i = [3,3,3,3,3,4,4,5,3,5,5,5]$<br>$d_i = [4,3,7,3,5,10,12,16,12,16,7,10]$ | (1,2) , (1,3) , (1,11) , (1,12) , (2,3) , (4,5), (6,9) , (12,6) , (8,1) , (9,1) |
| **DG8** | (5-9-12) | $a_i = [1,1,1,7,7,10,10,8,10,8,5,5,1,1]$<br>$h_i = [2,6,3,4,4,5,6,3,3,2,4,5,2,6]$<br>$p_i = [3,6,4,3,3,5,3,5,5,3,5,6,3,6]$<br>$f_i = [3,5,3,4,4,4,5,3,3,3,4,5,3,5]$<br>$d_i = [7,13,13,10,10,15,16,18,20,14,10,11,7,13]$ | (1,2) , (1,3) , (1,11) , (1,12) , (2,1) , (2,3), (4,5) , (4,13), (6,9) |
| **DG9** | (5-9-12) | $a_i = [1,3,2,1,7,10,7,7,10,10,5,5,2,1]$<br>$h_i = [3,4,2,2,4,6,5,4,4,5,4,5,2,2]$<br>$p_i = [5,5,3,4,5,4,6,5,2,4,5,6,3,4]$<br>$f_i = [5,5,3,4,4,5,5,5,3,4,4,5,3,4]$<br>$d_i = [6,8,5,5,12,14,13,12,12,14,10,11,5,5]$ | (1,2) , (1,3) , (1,11) , (1,12) , (2,1) , (2,3), (4,5) , (4,13), (6,9) |
| **DG10** | (5-9-12) | $a_i = [1,1,3,1,3,5,7,10,10,10,3,7,3,5]$<br>$h_i = [2,3,4,6,6,6,5,6,2,5,6,5,6,6]$<br>$p_i = [3,2,4,2,2,5,5,6,2,6,4,3,2,5]$<br>$f_i = [3,3,3,3,3,4,4,5,3,5,5,5,3,4]$<br>$d_i = [4,3,7,3,5,10,12,16,12,16,7,10,5,10]$ | (1,2) , (1,3) , (1,11) , (1,12) , (2,1) , (2,3), (4,5) , (4,13), (6,9) |

*Table 4: Numerical results of the adaptation of the exact method to solve small size instances of the Table 3*

| Instance name | Total (root+branch &cut) | Solution status | Optimal value | Continuous variables | Direct Transshipment vessel pairs | Indirect Transshipment vessel pairs |
|---|---|---|---|---|---|---|
| **DG1** | 0.14 sec. (56.33 ticks) | Optimal | 68.99999999999639 | $b_i$ =[9,1,7,5,1,1,1,6,8,9] $t_i$ =[5,1,1,7,710,15,10,15,8] $c_i$ = [8,7,5,10,10,15,18,15,20,11] | (9,7) | (1,3), (1,4), (2,4), (3,2) (4,6), (6,10) |
| **DG2** | 0.72 sec. (280.89 ticks) | Optimal | 168.0 | $b_i$ =[1,5,9,9,1,5,6,1,7,1] $t_i$ =[1,3,5,1,16,16,8,7,14,12] $c_i$ =[6,8,8,5,21,20,14,12,16,16] | (1,4) | (2,3 ), (7,9) |
| **DG3** | 0.16 sec. (78.49 ticks) | Optimal | 128.00000000000216 | $b_i$ =[9,7,7,3,1,1,1,1,1,6] $t_i$ =[1,4,6,1,3,5,12,17,10,10] $c_i$ = [4,6,10,3,5,10,17,23,12,16] | (10,9) | (1,3), (2,4), (2,6), (3,8), (3,9), (4,6), (4,7), (5,3), (5,7), (5,10), (6,5), (6,8), (6,9), (7,3), (7,6), (8,4), (8,7), (8,10), (9,6) |
| **DG4** | 0.14 sec. (72.23 ticks) | Optimal | 37.0 | $b_i$ =[3,9,1,1,7,5,1,1,8,5] $t_i$ =[5,2,4,1,1,4,7,10,9,8] $c_i$ = [7,4,6,4,4,8,10,13,12,10] | | (1,3), (1,4), (1,6), (2,4), (2,5), (3,2), (3,7), (3,8), (4,3), (4,6), (4,7), (5,2), (5,7), (6,4), (6,5) , (6,9), (7,4), (7,10), (8,7), (8,10), (9,8), (10,7) |
| **DG5** | 26.95 sec. (21775.71 ticks) | Optimal | 206.00000000000023 | $b_i$ =[5,1,8,1,1,1,5,1,8,4,7,6] $t_i$ =[7,1,1,10,7,18,10,13,19,13,5,13] $c_i$ = [10,7,5,13,10,23,13,18,24,16,10,19] | (2,3) | (1,3), (1,4), (1,12), (2,4), (4,6), (6,10), (9,7), (11,2), (12,2) |
| **DG6** | 93.52 sec. (66906.63 ticks) | Optimal | 330.00000000000114 | $b_i$ =[1,7,5,5,7,1,1,7,7,2,1,6,1,3,2,5] $t_i$ =[15,11,19,8,13,15,6,20,15,11,19, 8,13,15,6,20] $c_i$ = [6,8,5,9,20,1525,13,15,19,11,26] | | (1,3), (1,4), (1,12), (2,3) , (2,4), (4,6), (6,10), (9,7), (11,2), (12,2) |
| **DG7** | 0.72 sec. (425.34 ticks) | Optimal | 268.0 | $b_i$ =[9,1,7,5,1,1,1,1,9,6,1,1] $t_i$ =[3,1,6,1,3,18,12,23,10,12,5,9] $c_i$ = [6,3,10,3,5,23,17,29,12,18,9,12] | | (1,3), (1,4), (1,12), (2,3) , (2,4), (4,6), (6,10), (9,7), |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | (11,2), (12,2) |
| **DG8** | 2196.97 sec. (1903801.18 ticks) | Optimal | 334.0000000000016 | $\boldsymbol{b_i}$ =***[7,1,8,1,5,6,5,8,8,9,1,1,9,2]*** $\boldsymbol{t_i}$ =***[1,1,4,7,8,14,11,19,24,8,10,15,1,21]*** $\boldsymbol{c_i}$ = [***4,7,8,10,11,19,14,24,29,11,15,21,4,27,***] | (1,13) | (1,3) , (1,4) , (1,12), (2,4), (3,2), (4,6), (4,14), (6,10), (9,7), (11,2), (12,2), (14,5) |
| **DG9** | 3205.16 sec. (2548575.38 ticks) | Optimal | 383.00000000000153 | $\boldsymbol{b_i}$ =***[1,5,5,9,6,5,1,1,7,1,1,6,7,9]*** $\boldsymbol{t_i}$ =***[1,5,2,5,22,12,20,11,10,16,2,1]*** $\boldsymbol{c_i}$ = [***6,10,5,9,27,16,26,16,12,20,11,22,5,5***] | (2,4) | (1,3), (1,4), (1,12), (1,13), (3,2) , (4,6) , (4,14) , (6,10) , (9,7) , (11,2) , (12,2) , (14,5) |
| **DG10** | 3.17 sec. (1777.45 ticks) | Optimal | 452.9999999999999 | $\boldsymbol{b_i}$ =***[7,1,7,4,1,5,1,1,9,6,1,1,1,5 ]*** $\boldsymbol{t_i}$ =***[3,1,6,1,3,30,14,24,10,12,7,11,5,19]*** $\boldsymbol{c_i}$ = [***63,10,3,5,35,19,30,12,18,11,14,7,24*** ] | (2,4) | (1,3), (1,4), (1,12), (1,13), (3,2) , (4,6) , (4,14) , (6,10) , (9,7) , (11,2) , (12,2) , (14,5) |

*Table 5: Description of medium sized instances*

| Instance | (N1, N2, B) | Parameters values | Transshipment vessels pairs |
|---|---|---|---|
| **Inst1** | (9, 11, 20) | $a_i = [1,6,7,2,1,6,1,4,9,10,12,13,9,17,17,17,17,20,20,20]$ $h_i = [4,5,3,2,6,4,6,6,3,4,6,4,3,4,3,55,5,3]$ $p_i = [4,5,3,4,5,5,3,5,3,5,5,4,4,3,3,5,3,6,6,5]$ $f_i = [3,4,3,3,5,4,3,4,3,4,5,4,4,3,3,4,4,4,4,3]$ $d_i = [5,11,10,6,6,12,4,9,12,16,17,17,13,20,20,22,20,26,26,26]$ | (2,4) , (2,6) , (14,15), (15,16), (16,13) |
| **Inst2** | (13,12, 20) | $a_i = [1,1,1,1,1,1,4,4,4,4,4,4,7,7,7,7,7,7,10,10,10,10,10,10,13]$ $h_i = [3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3]$ $p_i = [3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3]$ $f_i = [4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4,4]$ $d_i = [10,10,10,10,10,10,7,7,7,7,7,7,10,10,10,10,10,10,13,13,13,13,13,13,16,]$ | (1,7) , (2,3) |
| **Inst3** | (17,13, 20) | $a_i = [1, 1, 1, 1, 1, 2, 4, 4, 4, 4, 4, 4, 7, 7, 7, 7 ,7 ,7, 10, 10, 10, 10, 10 ,10 ,13, 13, 13, 13, 13, 13]$ $h_i = [3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,]$ $p_i = [3, 3 ,3 ,3 ,3 ,2, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3, 3 ,3 ,3 ,3, 3, 3, 3, 3, 3]$ $f_i = [4 ,4, 4, 4, 4, 4, 4, 4, 4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4 ,4, 4, 4, 4, 4, 4, 4, 4]$ $d_i = [10, 10, 10 ,10, 10, 10, 7, 7, 7, 7 ,7 ,7 ,10, 10, 10, 10, 10, 10, 13, 13, 13, 13, 13, 13, 16, 16, 16, 16,$ … | (1,7) , (2,3) |
| **Inst4** | (17,13, 20) | $a_i = [ 1,1,1,1,1,1,1,1,1,3,3,3,3,3,3,3,3,5,5,5,5,5,5,5,5,9,9,9,9,9,9,9,9,13,13,13]$ $h_i = [2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2]$ $p_i = [ 2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2,2]$ $f_i = [ 3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3,3 ]$ $d_i = [5,3,3,3,3,3,3,3,3,7,7,7,7,7,7,7,7,7,11,11,11,11,11,11,11,11,11,15,15,15]$ | (1,20) |

*Table 6: Numerical results of the adaptation of the exact method and the GA on the instances of the Table 5*

| Instance no & name | CPLEX | | | GA | | |
|---|---|---|---|---|---|---|
| | **Obj Val** | **CPU(s)** | **Dev** | **Obj Val** | **CPU(s)** | **Dev** |
| **Inst1** | 87.0 | 0.98 | 0 | 87 | 5.609928 | 0 |
| **Inst2** | 90.0 | 0.16 | 0 | 90 | 1.149060 | 0 |
| **Inst3** | 75.0 | 0.16 | 0 | 75 | 0.607894 | 0 |
| **Inst4** | 60 | 0.17 | 0 | 64.2296 | 2.996758 | 4.2296 |

# Calculation of transport system in flexible manufacturing


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## Abstract

Modern enterprises deal with a number of different material fluxes with respect to the transportation and storage systems, which can be considered as two parts of a whole warehouse system in a flexible manufacturing. At that, the warehouse system is considered as a regulator of the flows to compensate the uneven production in the enterprise or uneven delivery from outer suppliers. Up to date, the methods of the warehouse design rely mostly on the average indicators; however, they require the statistical data that are not always available, especially at the preliminary design stage. As a result, insufficient storage or transport capacity can form a 'bottle neck' that decreases the effective output of the enterprise.

Thus, the implementation of the methods that considered the probabilistic character of the storage and delivery processes is necessary to avoid the miscalculation. Using the methodology of theory of mass service like the queuing theory, the capacity of the transport system can be determined without preliminarily collecting statistical data on the materials flows of arrival and departure, as well as processing these materials by methods of mathematical statistics and probability theory.


## 1. Introduction

A factory planning involves a lot of problems that should be solved to avoid critical mistakes, which hinder the effective exploitation of the flexible manufacturing systems [1]. For the purpose, statistical methods of analysis of such systems, like queuing theory [2] powered by simulation [3] are applied, as was successfully demonstrated for theoretical calculations of flow-type [4] and flexible manufacturing systems [5], as well as for industry applications [6-9].

However, the problem is far from being solved due to the large variety of FMS. In our previous work, the application of queuing theory was demonstrated with respect to a particular type of a system that incorporates CNC cutting machines provided with the machine-bound buffer magazines and large inter-operational storage for workpieces. At that, the methods of calculating the capacity of the buffer magazines and inter-operational storage were developed [10], as well as methods of calculation of the number of lines for robots to provide CNC machines with tools, and method of calculation of the capacity of a section in the central tool storage [11]. However, since flexible manufacturing systems are a highly integrated systems, where the relation between components is very complex, various mathematical programming approaches are in-demand.

Generally, the methodologies developed for optimization of robocar transport systems are categorized into mathematical methods (exact and heuristics), simulation studies, meta-heuristic techniques and artificial intelligent based approaches [12]. Suri et al. represented one of the first works in automated manufacturing of parts with mid-volume demand, where a computer program based on mean-value analysis of queues was developed [13]. An algorithm proposed by Mahdavi et al. [14] was dedicated to solution of major challenges in the domain of autonomous transportation systems, which are trajectory planning and collision avoidance. In the first phase, the lowest cost path is planned by a modified Dijkstra algorithm; in the second phase, the head-on collisions can be foreseen and avoided, and finally, the task assignment and scheduling algorithm allocated different tasks. A distributed Petri net was applied by Herrero-Perez et al. [15] for solving task allocation and traffic control problems. Petri nets and algorithm with a heuristic function represented by a neural network, were also proposed by Nie et al. [16] to simulate an operation of a robotic system in the numerical experiments to estimate a minimal time that should be taken to complete all planned tasks. A method based on use of the graphical language Sequences of Operations (SOP), was applied by Magnusson et al. [17] to automate transport planning for FMS. The method was composed of three iterative steps, which require create operations, add local execution conditions and extend the execution conditions to achieve a correct global behaviour. In the work conducted by Kumar et al. [18], an implementation of Flexsim model for measuring and analysis of FMS performance was tested. The approach developed by Fazly et al. [19] was concentrated on the design and optimization of FMS layout, where ARENA simulation software was employed. A mathematic model for integrated scheduling of a specific type of FMS with single robocar and single buffer area was developed by Lv et al. [20]. Unfortunately, the numerical experiments are time consuming, while the simulations of a separate systems lack generality.

In this paper, we report about the method of calculation of a transport system intended to serve CNC machines with a purpose of changing the processed workpieces to blanks by use of transport robocars. A developed mathematical model is based on the well-known model of death and reproduction that describes the states of the transport system according to the degree of loading of the storage area with transport consignments. Each of the states describe a certain probabilistic situation that is characterized by a fixed set of CNC unit engagement, rate of arriving requirements for CNC service, and service rate. The research question is formulated as following: what have to be the number of robocars of the

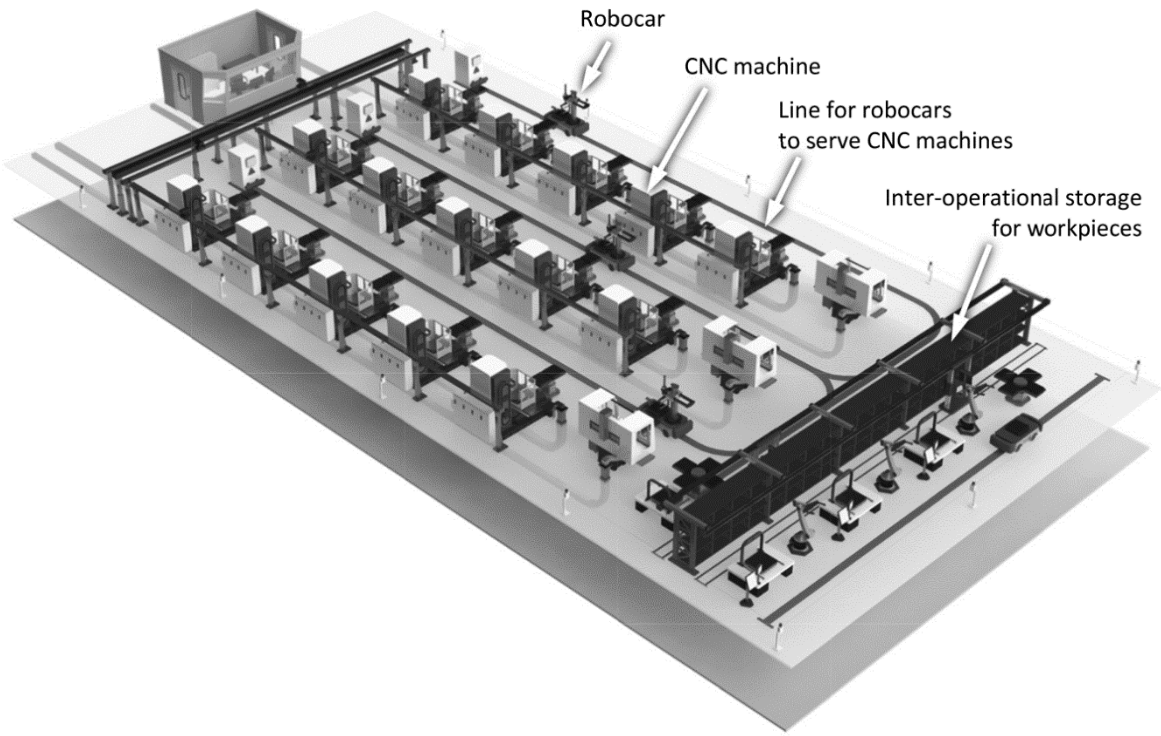


*Figure 1: General view of a machining flexible manufacturing system (FMS) with n CNC machines (n = 18) that are served by m robocars, which is considered in the paper*

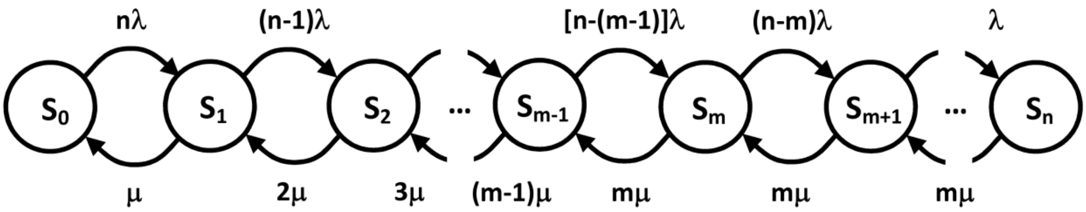


*Figure 2: Labeled graph of Markov process of the queuing system discussed in the paper*

transport system to fit the production rate of FMS of a specified design?

## 2. Methods

A flexible manufacturing workshop of a specified layout is considered. It includes CNC machines, and produces a certain number of workpieces of a wide nomenclature. A general view of the workshop provided with $n$ CNC units ($n$ = 18) is shown in Figure. 1.

To make a supply chain between the CNC machines and an inter-operational storage, the production and storage are connected by transportation lines for robocars, and the number of the robocars is $m$. At that, each of $n$ CNC machines requires servicing at a frequency $\lambda$ (workpieces/h), while each of $m$ robocars can serve the CNC machines at a rate $\mu$ (machines/h). It is assumed that each service requirement from the CNC machines equals to the delivery of one workpiece by use of one robocar. In a case when the robocar can deliver several workpieces in one transport consignment, the rate $\lambda$ of arriving requirements should be decreased by $N_{cs}$ times, where $N_{cs}$ is the number of workpieces in one transport consignment.

To determine the dependence of the average number $N_{ru}$ of robocars-on-duty on the number $m$ of robocars employed in the production system, as well as the robocar utilization $K_{ru}$, the average number of served CNC machines $A_{serv}$ (absolute service capacity of the transportation system), and the average number of idle CNC machines $N_{CNCidle}$, a dependence of probability $p_k$ of a certain state $k$ of the production system on the number of CNC machines $n$ at the number of employed robocars $m$ should be determined. For the purpose, a system of Kolmogorov equations is set to describe a process illustrated in Figure 2. The figure presents a labeled graph of Markov process of the queuing system, where $S_0$ is a state when all CNC machines operate, and all robocars are not on duty. At that, the total flow of requirements for service is $n\lambda$, since each of the CNC machines can produce the requirement. $S_1$ is a state when one CNC machine does not operate, and one robocar is on duty. The rate of transfer from $S_1$ to $S_0$ state is determined by the total service rate that is $\mu$, if the system stays in $S_1$ state (only one robocar is on duty); the rate of transfer to $S_2$ state is $(n\text{-}1)\lambda$, since one CNC machine has already produced the requirement for the service to a robocar, and cannot generate new requirement. $S_2$ is a state when two CNC machines do not operate, and two robocars are on duty, so the rate of transfer to $S_1$ state is $2\mu$, and the rate of transfer to $S_3$ state is $(n\text{-}1)\lambda$. $S_m$ is a state when $m$ CNC machines do not operate, and $m$ robocars are on duty. After all $m$ robocars are on duty, the total service rate $m\mu$ stays constant even if the number of CNC machines requiring service increase from $m$ to $n$.

Thus, the following set of differential equations that determines the rates of change of probabilities $p_k$ (k=0, 1, …, $n$) at the dependence on probabilities $p_{k-1}$ and $p_{k+1}$ can be written: (1)

$$
\begin{cases}
\frac{dp_0}{dt} = -n\lambda p_0 + \mu p_1, \\
\frac{dp_1}{dt} = n\lambda p_0 - [(n-1)\lambda + \mu]p_1 + 2\mu p_2, \\
\frac{dp_2}{dt} = (n-1)\lambda p_1 - [(n-2)\lambda + 2\mu]p_2 + 3\mu p_3, \\
\dots \\
\frac{dp_k}{dt} = \begin{cases} [n-(k-1)]\lambda p_{k-1} - [(n-k)\lambda + k\mu]p_k + \\ +(k+1)\mu p_{k+1}, \quad k < m \\ [n-(k-1)]\lambda p_{k-1} - [(n-k)\lambda + m\mu]p_k + \\ +m\mu p_{k+1}, \quad k \geq m \end{cases}
\end{cases}
$$

From a practical point of view, a stationary mode of the manufacturing system is usually a matter of interest, so the equations can be simplified by implying the following condition:

$$\frac{dp_k}{dt} = 0. \quad (2)$$

To solve system (1), a normalization condition should also be implied, which states that a sum of the probabilities $p_k$ should equal unity:

$$\sum_{k=0}^{n} p_k = 1. \quad (3)$$

To simplify further the final set of equation, a utilization factor is introduced

$$\alpha = \frac{\lambda}{\mu}, \quad (4)$$

and the probabilities $p_k$ of a certain state $k$ at the dependence on the number $n$ of CNC machines at the number $m$ of robocars employed in the production system and probability $p_0$ are expressed from system (1):

$$p_k = \begin{cases} \frac{\alpha^k}{k!}\frac{n!}{(n-k)!}p_0, & k < m, \\ \frac{\alpha^k}{m!m^{k-m}}\frac{n!}{(n-k)!}p_0, & k \geq m. \end{cases} \quad (5)$$

To determine the probability $p_0$ that is the probability of the state when all CNC units operate, and all robocars are not on duty, the last expression is substituted into (3), which yields:

$$\sum_{k=0}^{m-1}\frac{\alpha^k}{k!}\frac{n!}{(n-k)!}p_0 + \\ + \sum_{k=m}^{n}\frac{\alpha^k}{m!m^{k-m}}\frac{n!}{(n-k)!}p_0 = 1, \quad (6)$$

and $p_0$ is determined:

$$p_0 = \left( \begin{matrix} \sum_{k=0}^{m-1}\frac{\alpha^k}{k!}\frac{n!}{(n-k)!} + \\ + \sum_{k=m}^{n}\frac{\alpha^k}{m!m^{k-m}}\frac{n!}{(n-k)!} \end{matrix} \right)^{-1}. \quad (7)$$

Thus, final expressions for the probabilities $p_k$ are obtained:

$$p_k = \begin{cases} \frac{\frac{\alpha^k}{k!}\frac{n!}{(n-k)!}}{\sum_{k=0}^{m-1}\frac{\alpha^k}{k!}\frac{n!}{(n-k)!}+\sum_{k=m}^{n}\frac{\alpha^k}{m!m^{k-m}}\frac{n!}{(n-k)!}}, & k < m, \\ \frac{\frac{\alpha^k}{m!m^{k-m}}\frac{n!}{(n-k)!}}{\sum_{k=0}^{m-1}\frac{\alpha^k}{k!}\frac{n!}{(n-k)!}+\sum_{k=m}^{n}\frac{\alpha^k}{m!m^{k-m}}\frac{n!}{(n-k)!}}, & k \geq m. \end{cases} \quad (8)$$

After determining the probability of the states of the manufacturing system, other characteristics can be found. The average number $N_{ru}$ of robocars-on-duty is:

$$N_{ru} = \sum_{k=1}^{m-1} kp_k + m\sum_{k=m}^{n} p_k. \quad (9)$$

The robocar utilization is:

$$K_{pu} = \frac{N_{ru}}{m}. \quad (10)$$

The average number of CNC machines served by the robocars that is the absolute service capacity of the transportation system, is:

$$A_{serv} = \mu N_{ru}. \quad (11)$$

The average number of idle CNC machines, i.e. the machines that do not operate while waiting the service from the robocars, is

$$N_{CNCidle} = \sum_{k=1}^{n} kp_k. \quad (12)$$

## 3. Results of calculations

The proposed model was employed to calculate the efficiency of FMS with $n$ = 18 CNC machines with an average production capacity of 4 items/h; thus, each of the machines requires servicing with the parameter $\lambda$ = 4 workpieces/h. At that, rough estimation allows obtaining the number of robocars necessary to satisfy the requirements at the known service capacity $\mu$ of a robocar. In the example, the capacity was set to
$\mu$ =24 workpieces/h that correspond to the average service time of
60 min/24 workpieces = 2.5 minutes to change a workpiece in CNC machine. This value is quite reasonable, when considering typical length of transportation line of a few dozen meters, robocar velocities of about 30 m/min, and times of changing positions in the buffer storages near CNC cutting units. Thus, the average number of the robocars at such parameters should be $\lambda n/\mu$ = 4·18/24 = 3 robocars, which are engaged for 100 % at that, so the robocar utilization is unity. With such a high degree of utilization robocars cannot be exploited, their number have to be increased, which, in turn, leads to increase of production cost. However, application of the proposed mathematical model allows obtaining more accurate results.
The results of calculations by use of expressions (8) of the dependence of probability $p_k$ of a certain state $k$ of the production system on the number of CNC machines at the number of robocars $m_{rc}$ = 3 and $m_{rc}$ = 4 are shown in Figures 3 and 4, respectively.

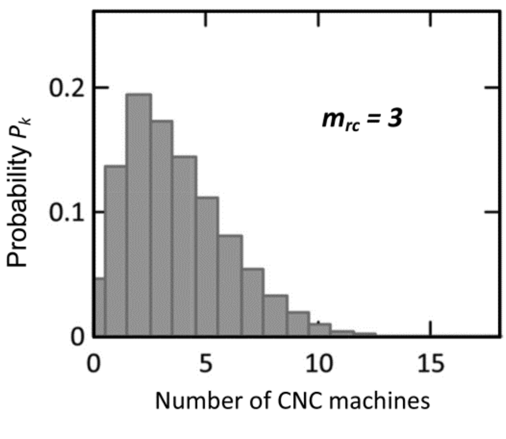


*Figure 3: Dependence of probability of a certain state of the production system on the number of CNC machines at the number of robocars $m_{rc}$ = 3*

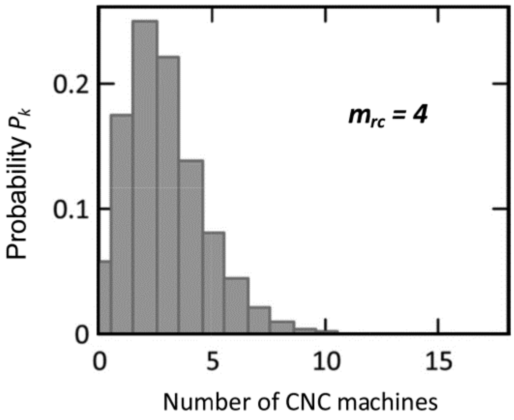


*Figure 4: Dependence of probability of a certain state of the production system on the number of CNC machines at the number of robocars $m_{rc}$ = 4*

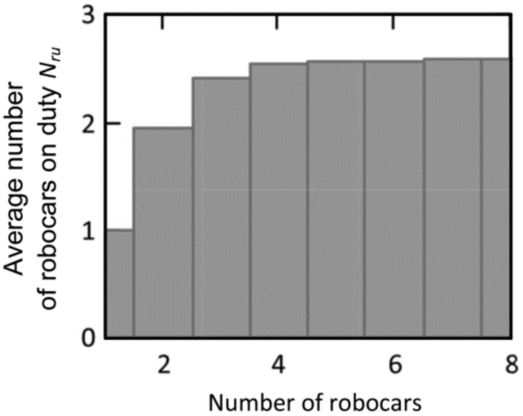


*Figure 5: Dependence of the average number of robocars-on-duty on the number of robocars employed in the production system*

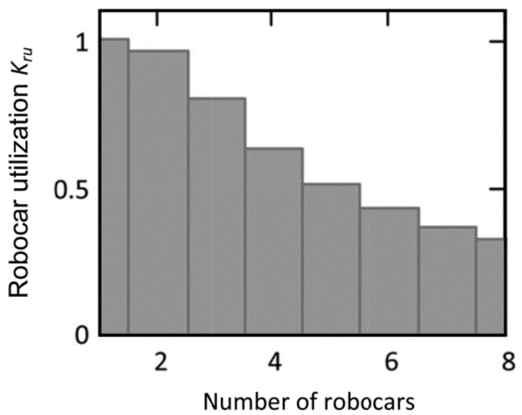


*Figure 6: Dependence of the robocar utilization on the number of robocars employed in the production system*

As it can be seen, for the fixed number of CNC machines $n$ = 18, the distribution becomes sharper at $m_{rc}$ = 4, while the most probable state is still the same, namely $S_3$. Moreover, if the number of robocars is increased further, the average number of robocars-on-duty does not change significantly, as it can be seen from the results shown in Figure 5. At that, the utilization factor shown in Figure 6, is satisfactory even for two robocars employed in the system, $K_{ru}(2)$ = 0.8, while the served number of CNC machines is not so far from saturation, as it can be seen in Figure 7, since $A_{serv}(2)$ = 57.6 (in the saturation limit this value reaches 61.7 machines/h). The average number of idle CNC machines in this case is $N_{CNCidle}(2)$ = 3.6 machines, as it follows from Figure 8. The robocar utilization for the cases $m$ = 1, 3, and 4 are $K_{ru}(1)$ = 0.966, $K_{ru}(3)$ = 0.632, $K_{ru}(4)$ = 0.512; the average number of served CNC machines are $A_{serv}(1)$ = 46.4, $A_{serv}(3)$ = 60.7, $A_{serv}(4)$ = 61.5; the average number of idle CNC machines are $N_{CNCidle}(1)$ = 6.4, $N_{CNCidle}(3)$ = 2.8, $N_{CNCidle}(4)$ = 2.6.

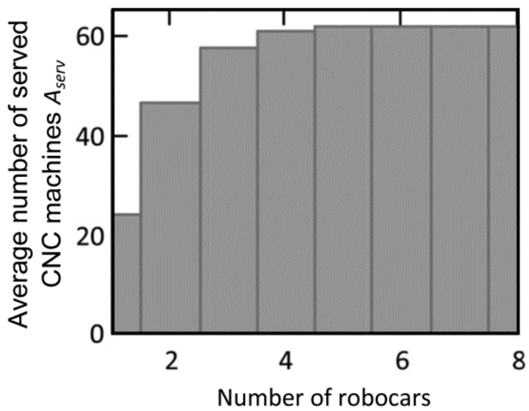


*Figure 7: Dependence of the average number of served CNC machines on the number of robocars employed in the production system*

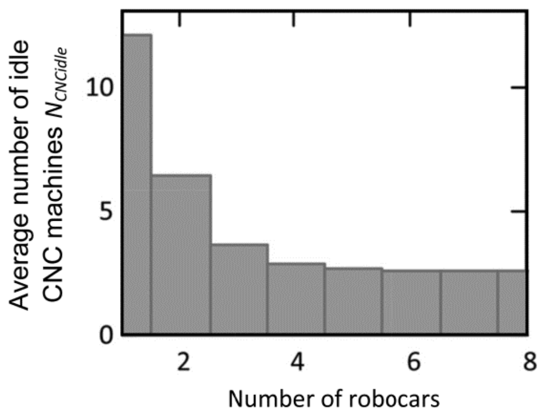


*Figure 8: Dependence of the average number of idle CNC machines on the number of robocars employed in the production system*

Thus, even two robocars can satisfy the requirements from CNC machines in this system; however, it is appropriate to use tree robocars to increase reliability.

## 4. Summary

The developed model was used to calculate the parameters of efficiency of a storage system of a flexible manufacturing by use of methods of queuing theory. It was shown that the calculations allows solving a problem of estimation of a number of robocars employed to serve CNC cutting machines in flexible manufacturing. For a specified number of CNC machines, the necessary number of the robocars is lesser that obtained by use of average values of productivity $\mu$ of the robocars, and $\lambda$ – for CNC machines. In turn, the economy obtained due to more accurate calculations, results in increase of the cost-efficiency of the whole production cycle.

In future, the methods of the queuing theory are planned to be used to predict the efficiency of the whole transportation and storage system of such FMS, including the states of the large inter-operational storages with their transport facilities.

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# Future Application of VSM in Digitalized Environments

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## Abstract
Value stream management is one of the most applied methodologies to map, analyse and improve end-to-end supply chains from a company's perspective. By its application wastes in the logistics value streams, e. g. waiting times, negatively effecting the product's lead time are identified and eliminated in a structured way. The paper at hand deals with the topic of the future viability of the traditional value stream method, especially the value stream mapping against the background of growing system design opportunities, offered by fast technology developments in context of industry 4.0. In detail, the paper refers to the increasing digitization and digitalization of operational processes in the domains of logistics and production. Therefore, the current state of research regarding the impact of information and communication technologies (ICT) on the traditional value stream method and its potential in regard to the improvement of complex supply chains is investigated. For this purpose, a literature review according to PRISMA [1, pp. 1–4], [2, pp. 1–9] is followed with the aim to determine the research status quo, from which a research gap is derived.

## 1. Introduction
In a globalised world, manufacturing companies are in competition with their entire supply chains. Volatile markets necessitate increasing flexibility to ensure a company's competitiveness by the ability of agility. Key prerequisite is a deep market knowledge, fostered by transparency along all stages of the supply chain. In this context digital technologies have an important role, enabling the recording and provisioning of real-time data as well as the automated recognition of pattern in big data pools, supporting decision-making activities. [3]
Value stream management is related to the principles, methodologies and tools of lean management and represents a holistic framework for structured decision making in context of supply chains. [4, pp. 622, 623] Additional to the company's internal logistics processes also external material and information flows from suppliers and to customers are considered. The method can be divided into four phases, which are named value stream mapping (VSM), value stream analysis (VSA) and value stream design (VSD) and value stream planning (VSP). [5, pp. 249, 250], [6] The present paper is limited to the first phase VSM.
The value stream method is a well-known and field-tested approach, applied by companies to improve logistics related processes, also taking production-related activities into account. In detail, the method supports the structured reduction of the overall lead time by eliminating wastes, e. g. stocks, which negatively affects the material flow. Therefore, a quantitative comparison of value-adding durations and non-value-adding durations is performed to calculate the effective lead time as sum of both types of duration and a key performance indicator for measuring the process efficiency as ratio of both values. [7, pp. 2–6]
The procedure of the traditional value stream mapping is characterized by a time consuming and effort intensive procedure, caused by manual-driven recording of process steps, WIP stocks and cycle times during an on-site-visit. Several production cycles are measured, documented and consolidated to an average to ensure a valid data base, cleansed from potential measurement errors. [7, pp. 1, 6–12], [8, p. 3066] Changes in the value stream necessitate a new end-to-end recording, what indicates the rigidity in connection with dynamic surroundings, requiring more flexible

structures. [9, pp. 1, 2] This issue is considered in some publications which differentiate the traditional value stream method as static VSM due to its rigid data base and the flexible, optimized VSM as dynamic one. [10], [11]
These circumstances lead to the central question, if the value stream method in its traditional setup is still a reasonable tool for optimizing value streams from the perspective of a company, strived to reduce wastes in a more and more digitized and digitalized environment. Furthermore, the question is, if synergies by integrating ICT can be achieved and how.
Prior studies refer to these scientific issues from various perspectives and on different levels of detail. The references are named and analysed in the following sections. Aim of the paper at hand is the determination of the current state of research to designate in a second step the concrete research gap. To achieve this, a systematic literature review on appropriate topic-related literature is carried out.

## 2. Applied Methodology

By a combined search for key words regarding the value stream method and key words regarding industry 4.0 an extensive selection of studies and literature can be found, making the alignment of the traditional value stream method and technologies in context of industry 4.0 a subject of discussion. Following the paper's is aim, mentioned in the previous section, a systematic literature review is carried out according to the PRISMA approach, which is briefly described below.

**Systematic literature review according to PRISMA**
Initially published in 2009, PRISMA, an acronym for "Preferred Reporting Items for Systematic reviews and Meta-Analyses ", describes a guidance for systematic literature review, providing a checklist for a completeness check concerning the reporting of systematic reviews or meta-analyses as well as a flow chart, dividing the whole review process into specific phases. Each phase consists of steps, referred to the checklist, which aim at the structured concentrating of the data source to excluded not relevant sources. [1, pp. 2, 5, 6, 8]
The PRISMA 2020 statement is an update of the described approach. Therefore, the checklist and the flow chart were reworked to take findings gained from systematic reviews during the last decade into account. Thereby, some items are dropped, new items are added and some items were described more detailed. However, the core process remains on a gross level, even if the phases are more specific and not named anymore as in the former publication from 2009. [2, pp. 1, 2, 5–8]
In essence, the underlying methodology follows the PRISMA scheme, visualized in the figure below.

The three phases are detailly described in the following sections.

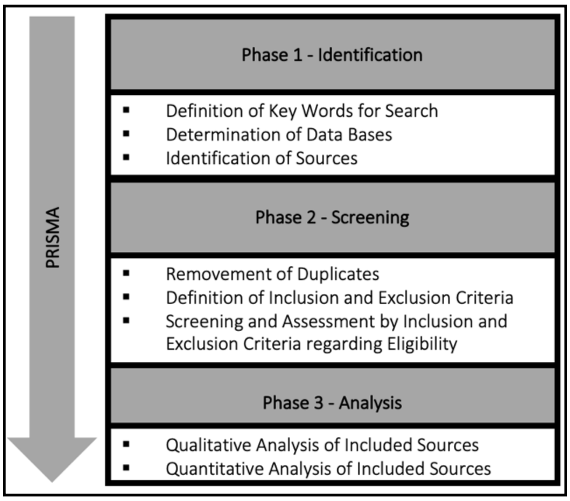


*Figure 1: PRISMA Scheme [1, p. 8], [2, p. 8], [12, p. 5]*

**Phase 1 – Identification**
In the framework of the PRISMA approach the key words for search were taken into account:

- „Wertstrom 4.0"/ "Wertstrom 4.0"
- „Wertstromanalyse 4.0"/ "Wertstromanalyse 4.0"
- „VSM 4.0"/ "VSM 4.0"
- „Value Stream Mapping 4.0"/ "Value Stream Mapping 4.0"
- „Dynamische Wertstromanalyse"/ "Dynamische Wertstromanalyse"
- „Dynamic VSM"/ "Dynamic VSM"
- „Dynamic value stream mapping"/ Dynamic value stream mapping"

As data bases the scientific knowledge libraries were used (date of access: 02/07/22):

- ResearchGate (https://www.researchgate.net)
- Google Scholar (https://scholar.google.com)
- IEEE Xplore (https://ieeexplore.ieee.org/)

The raw search results are documented in an Excel-based table to apply filter operations and meta-analyses. The results of each analysis are described in the following section of the paper at hand.
In phase 1 N = 1258 records were identified. It is pointed out, the search result at Research Gate is limited to an output of N = 100 records for every search operation, tried out during the systematic literature review. Regarding the used key words, every search cycle resulted in N = 100 records. For this reason, the completeness of these search cycles cannot be ensured. The table below gives an overview of the search results related to data base and key word for search. To ease the readability,

the applied interpunction for searching is not considered in the table.

*Table 1: PRISMA Identification Result – Phase 1*

| Search Key Word | Data Base | Records |
|---|---|---|
| **Wertstrom 4.0** | ResearchGate | 100 |
| | IEEE | 0 |
| | Google Scholar | 5 |
| **Wertstromanalyse** | ResearchGate | 100 |
| | IEEE | 0 |
| | Google Scholar | 43 |
| **VSM 4.0** | ResearchGate | 100 |
| | IEEE | 0 |
| | Google Scholar | 48 |
| **Value Stream Mapping 4.0** | ResearchGate | 100 |
| | IEEE | 3 |
| | Google Scholar | 146 |
| **Dynamische Wertstromanalyse** | ResearchGate | 100 |
| | IEEE | 0 |
| | Google Scholar | 4 |
| **Dynamic VSM** | ResearchGate | 100 |
| | IEEE | 0 |
| | Google Scholar | 64 |
| **Dynamic value stream mapping** | ResearchGate | 100 |
| | IEEE | 1 |
| | Google Scholar | 244 |

In sum, the overall search result contains N = 1258 records (ResearchGate N = 700, IEEE N = 4 and Google Scholar N = 554).

**Phase 2 – Screening**

After consolidating all records from the different data bases, all duplicates are removed. Further on, the inclusion and exclusion criteria are defined. All records are excluded, which do not fulfil the inclusion criteria, mentioned in the listing below.

- The record is in German or English language.
- The record belongs to the document type article, thesis, conference paper or chapter.
- The record is directly or indirectly related to the search topic and its relevance is proven.
- The record is available as full-text. If not, but the abstract suggests a significant insight into the record's content, the record is included with restrictions.

Applying the availability check, two categories are differentiated according to the last criteria. The result is shown in the following table.

Table 2: PRISMA Screening Result – Phase 2

| Category | Characteristic | Records |
|---|---|---|
| **Cat. 1** | Full-text available | 28 |
| **Cat. 2** | Full-text not available, but adequate abstract | 13 |

Even if the content of a record is summarized in the record's abstract and key words are highlighted, the integrative consideration of these records happens on a gross level and deeper analyses on the content in detail are constrained. However, the abstract provides a thematical tendency and must be included for an entire view. Therefore, in the following tables the quantities of full-texts and abstracts are pointed out separately, keeping this limitation of review in mind.

## 3. Results and Discussion

Based on the procedure, elucidated and reasoned in the former section, the baseline for the analyses is N = 41 records.

**Phase 3 – Analysis**

In general, the record's context can be differentiated into two thematical streams. For three-fourth of the reviewed records (N = 30) the methodology of VSM in context of digitalization according to the principles of industry 4.0 is the major topic (e. g. [13]–[15]) whereas for one-fourth of the records (N = 11) the horizon of consideration is widened to a holistic review of lean management as a whole (e. g. [12], [16], [17]). Due to the widened view of the second stream the level of detail regarding the analysis of VSM is lesser. In total, all records have in common, ICT are an important factor, impacting the future application of VSM. By the utilization of ICT in an increasingly digitized environment the volume of available data grows. For this reason, on the one hand the control of information flow gets more important. On the other hand, ICT foster transparency by providing real-time data of processes, which ease the tracking and tracing of value streams in the domains of production and logistics. The consideration of ICT in relation to the traditional VSM follows two approaches, as pointed out in [18]. Both approaches aim at the extension of the traditional framework, but in different ways.

For the first approach the standard procedure remains. During on-site visits the documentation of VSM-related KPI is enriched in regard to the digital information flow. In detail, the records refer to the documentation of the information storage media and its usage, visualized by visualized by swim lanes below the traditional value stream map as well as its flow direction from the activity's perspective (into or out of), illustrated by directed arrows. The approach's central target is the identification of media breaks and technical instabilities, which cause wastes in the handling of information. The knowledge regarding weaknesses in the information flow allows the structured improvement and harmonization of the process and system landscape from a technology perspective. [5], [13, pp. 93–102], [15], [19]–[21] Additional one record suggest the enhancement of the traditional VSM by technology-driven KPI, to be recorded for each activity in the value stream. In detail, the three KPI vertical and horizontal integration rate, material and information automation rate and digitization rate are stated. [22], [23]. A utilization of digital data for improving the methodology itself is not considered. As described in the former sections, the traditional VSM is primary a pen-and-paper process and, therefore, time- and effort-intensive. Already mentioned disadvantages of the traditional procedure, reinforced by dynamic environments, decreasing lot sizes, shorter innovation and product cycles as well as wider variety can be eliminated by significantly reducing the recording efforts. The second approach aims at the utilization of real-time and historical data gathered from the production and logistics processes by ICT to automate the mapping of value streams (process documentation). Moreover, the integrative orchestration and exploitation of real time data increases transparencies and accuracy in the value stream map. Beside the automated documentation in context of mapping the value stream the approach enables taking countermeasures in short time in case of deviations in the planned processes based on experiences gained from former production cycles (process monitoring). By the operational application of technologies materials can be identified and tracked, sensed and positioned as well as located. The following tables gives an overview of the distribution of the framework type, mentioned in the reviewed records.

*Table 3: Type of VSM Framework Extension*

| Framework Extension Type | Full-Text | Abstract | Records |
|---|---|---|---|
| **Documentation** | 7 | 1 | 8 |
| **Technology Utilization** | 21 | 12 | 33 |

Regarding the scope of technologies, utilized for automate mapping in context of VSM, the reviewed records can be distinguished according to the application of one single technology or a combination of several ones to one holistic solution, called system. In general, the following single technologies and technological systems are mentioned in the reviewed records:

- ID-technologies (e. g. RFID, barcode)
- Wireless technologies (e. g. wireless sensor network, Zigbee, Cloud computing)
- Big Data
- Machine learning
- Process mining
- Simulation
- Industry 4.0 ICT (in general)
- Positioning systems
- Cyber-physical systems (CPS)
- Digital twin/ digital shadow
- IoT and IIoT
- Application systems (e. g. ERP, MES and WMS)

Technological systems are based on the targeted combination of elementary technologies (CPS are amongst others based on wireless sensors, actuators and IoT). For this reason, a clear distinction and classification of the named technologies and systems is not possible. Indeed, the mentioned technologies are characterized by intersections.
The following referencing of technologies does not comprise completely all records, which relate to the named ICT and are therefore counted in table 4, but is a selection of exemplary records, which primary focus on its utilization.

*Table 4: Potential Technologies for VSM 4.0*

| Technology | Full-Text | Abstract | Records |
|---|---|---|---|
| **RFID/Auto-ID** | 10 | 4 | 14 |
| **Wireless Technologies** | 4 | 2 | 5 |
| **Big Data** | 6 | 0 | 6 |
| **Machine Learning** | 6 | 1 | 7 |
| **Process Mining** | 1 | 3 | 4 |
| **Simulation** | 7 | 0 | 7 |
| **Industry 4.0 ICT** | 10 | 2 | 12 |
| **Positioning System** | 1 | 0 | 1 |
| **Cyber-Physical System (CPS)** | 5 | 0 | 5 |
| **Digital Twin** | 2 | 1 | 3 |
| **IoT/IIoT** | 7 | 1 | 8 |
| **Application System** | 4 | 1 | 5 |

Mainly the deployment of RFID – or similar technologies to support the identification and tracking of material movements is proposed. [14], [24]–[26] As enhancement of RFID the application of a holistic indoor positioning system (cameras, optical sensors and more) is suggested to benefit from real-time positional data. The data analysis allows the evaluation of non-value-adding activities, also called wastes, especially regarding waiting times, stocks and transports, which cannot be directly derived from RFID data. [27] In the same context the usage of wireless network in general [28] and wireless sensors or Zigbee [29], [30] in particular are mentioned to gather more process-orientated data, which can be analyzed by procedures of big data analytics and can support machine learning and decision making algorithm. [4], [31], [32] Following the tendency of wireless technologies, Internet of Things (IoT) and Industrial Internet of Things (IIoT) [11], [33] for the communication between objects by network to establish a digital twin [4], respective a digital shadow [34] to link the physical and digital worlds are introduced. Furthermore, the implementation of cloud computing to merge the collected data from different technologies at one place is described [35]. To put the named features into a nutshell, the term of cyber-physical system, abbreviated CPS, is mentioned to take the bilateral interaction between both worlds into account. [36]–[38] In addition, in some records industry 4.0 technologies without any reference to a concrete technology are pointed out as potential for improvement of the traditional lean managements methods in general and VSM in particular. [39]–[41]

Regarding the recording, preparation and provision of operational data the utilization of process mining operations is recommended to automate the mapping process. [42]–[44] The creation of a data model forms the base of extensive operations, e. g. the simulation of business scenarios based on changing parameters. Even if simulations do not support primarily the automation of the mapping procedure of VSM, because the existence of a simulation model is prerequisite for the execution of simulations, the drawn scenarios underline the potential of a data-driven models in the design of value streams. [14], [45], [46]

To sum it up, regarding the second approach a mix of concrete technologies and technological systems is mentioned for automate the mapping methodology of value streams in dynamic environments and gathering findings out of the available data pools. All records refer to generalized frameworks, outlining technologies, but mainly missing a specific implementation scheme, in general and a concrete reference model for deriving VSM elements und KPI from the accessible data, in particular.

Beside the technology-focused approaches, operational respective business application systems are pointed out as potential data sources, bringing the sensor data into a reference framework (e. g. optical sensors signal for counting production quantities). As examples for application systems the categories ERP, MES, WMS and SCM are pointed out, but as for the technology-focused approach without outlining any concrete design details for such a data framework. [47]–[49]

The quantities of records, mentioning each type of technology, are shown in the following table. The consideration is limited to the view on records related to the technology framework. Due to the fact, some of the records refers to more than one technology, the sum of all quantities is greater than the total of N = 33 records.

As part of the meta-analysis the historical development of the number of publications, referring to the paper’s topic, is analyzed to evaluate the relevance of this topic. A structured overview is provided by the following table.

*Table 5: Historical Distribution of Publications*

| Year of Publication | Full-Text | Abstract | Records |
|---|---|---|---|
| **2012** | 0 | 1 | 1 |
| **2013** | 0 | 0 | 0 |
| **2014** | 0 | 1 | 1 |
| **2015** | 0 | 0 | 0 |
| **2016** | 4 | 1 | 5 |
| **2017** | 2 | 1 | 3 |
| **2018** | 6 | 1 | 7 |
| **2019** | 4 | 3 | 7 |
| **2020** | 6 | 1 | 7 |
| **2021** | 6 | 2 | 8 |
| ***(2022)*** | (0) | (2) | (2) |

The first record was already published in 2012, but the topic did not seem to have the scientific relevance as it has today. Only from 2016 on, the number of publications was greater than one and remains constantly between 7 and 8 in the years 2018 to 2021. The historical development shows the increased relevance during the last years. In 2011 the term industry 4.0 was introduced the first time as a holistic technology concept, but its realization depends on the development of performant technologies at low prices, which ensure an economical use. As described in the former sections the digitalization of VSM is mainly pushed by reasons of (economic) efficiency. Technologies own an enabler role regarding this issue. Costs decrease, while performance and availability increase. This trend fosters the relevance of combining digital technologies and lean management in general and VSM in particular.

## 4. Conclusion

In conclusion, the core of the value stream method is also in connection to an increasingly digitized

and digitalized environment an appropriate tool for enterprises to map, analyse and improve supply chains, especially regarding logistical material handling and information flows. But for its future application extensions and adaptions with regard to the application of ICT are required to ensure the economic efficiency as reasoned in the former sections. Its scientific relevance is underlined by the historical development of publication counts during the recent years. Different approaches are followed to increase the transparency in value streams and take advantage of the increasing technology utilization in supply chains, e. g. RFID, (I)IoT, cloud computing, (GPS-controlled) positioning systems and so on. In general, the targeted application of ICT in supply chains offers high efficiency potentials and enables VSM to become future-proof. In this context two approaches are distinguished – a documentation and a technology-orientated one. With regard to the second approach and applying the automation pyramid for the classification of technologies, visualized in the figure below, it is constituted, the reviewed records in the paper at hand are mainly focused on ICT, assigned to the categories L 0 – fields level, L 1 – control level and L 2 – supervisory level. The utilization of technologies of L 3 – planning level and L 4 – management level, especially business application systems is less covered, but more pointing out potentials for future developments of VSM.
These issues lead to three central questions, constituting the research gap.

- How can the data of L 3 and L 4 technologies in combination with data, processed by L 0, L 1 and L 2 technologies be utilized, to improve/ automate the value stream mapping in complex supply chains?
- What kind of data is required and which type of business application system is a suitable data source for the automation of the value stream mapping?
- How can the data be extracted, transformed and transferred into a concrete data model, forming a universal reference model for different use cases?

Dealing with the above-mentioned research questions is topic of following studies.

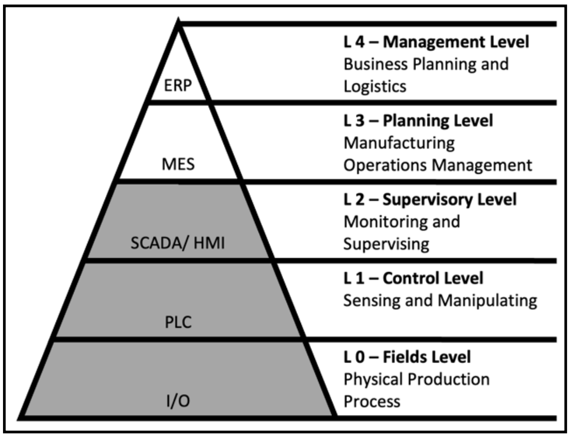


*Figure 2: Automation Pyramid for Classification of Technologies [50, p. 3]*

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# Participating Institutions

# 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 logistics research include:

- Mathematical modelling and simulation
- Development of instruments for analysis and planning
- The conservation of resources, energy efficiency and sustainable logistics
- Discrete element mthod simulation in continuous conveying technology
- Virtual engineering
- Ramp-up management
- The transfer of methodology and know-how in logistics
- Resilience in SCM
- Logistics 4.0

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 9.500 students and 160 post-graduate students are trained at the University; 650 teachers and 2.500 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 80000 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.

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 Le Havre Normandy

The University of Le Havre Normandiy (ULHN) was established in 1984 and it now counts over 8200 students. It is committed to supporting personal and professional development of all its students.
The ULHN is composed of three Training and Research Units –Teaching and Research Unit of Sciences and Technology, Faculty of International Affairs, Teaching and Research Unit of Arts and Humanities – of a University Institute of Technology, an Engineering School, a Higher Institute of Logistic and different departments.

Based on the transversality of disciplines, the research strategy of the University of Le Havre is built around four poles formed by research teams recognized by the Ministry of Research and/or associated with the CNRS or INERIS:

- the Human and Social Sciences (SHS) division,
- the Sciences for Engineers division (SPI),
- the Mathematics-IT division,
- and the Chemistry-Biology pole.

This interdisciplinarity is declined through three axes whose scientific corpuses are intended to aggregate and feed each other:

Axis 1: Territories, logistics, environment and complex systems,
Axis 2: Energy transition: technological, social and economic challenges
Axis 3: Culture, heritage, memory, identity.

Recognized by the Ministry of Research and Higher Education as one of the sixteen "Innovative Campuses" in France, the University of Le Havre is a stakeholder in the Normandy University community of universities and establishments.

Research at the University of Le Havre in figures:

- 1984: beginnings of university research in Le Havre
- 12 laboratories (6 in exact sciences, 6 in human and social sciences)
- 300 teacher-researchers and 230 doctoral students

www.univ-lehavre.fr

# Magdeburg-Stendal University of Applied Sciences (h2)

Since the Magdeburg-Stendal University of Applied Sciences was founded in 1991, it has earned an excellent reputation for a well-founded academic education and for a committed student body. Prospective students can choose from around 50 courses at three departments in Magdeburg and two departments at the Stendal site. Around 130 professors guarantee a very good supervision rate for around 3,700 students in Magdeburg and more than 1,800 in Stendal.

The research profile at the Magdeburg-Stendal University of Applied Sciences is characterized by future-oriented research and development activities tailored towards key markets in the state of Saxony-Anhalt and the requirements of regional businesses and institutions. To this end a large number of innovative research and development projects in the fields of engineering, economics, public health, communications and the social sciences is implemented. By concentrating specific skills in a number of competence centres it is possible to take a holistic, cross-disciplinary approach to research themes.

At the Magdeburg-Stendal University of Applied Sciences there are a total of 9 main research areas, from electrical engineering and information technology, innovative technologies, machines and components to water and recycling management. In the concrete field of application of the economy, the focus is on the following research topics:

- Management in the fields of public health, service provision, and demographics
- Entrepreneurship and risk management
- Production and process management and simulation
- Logistics and Digitalization
- Technology and investment management
- Marketing, especially for regional enterprises, institutions, and networks
- Change and sustainability management
- Staff development and inter-cultural competence

Since 2022, the Magdeburg-Stendal University of Applied Sciences has made it possible to do a PhD in the cross-university doctoral centre "Social, Health and Economic Sciences" in association with the universities of applied science of Anhalt (HSA), Harz and Merseburg and in the university's own doctoral centre "Environment and Technology". Already in the first phase of the acceptance applications, four doctoral projects in the context of logistics and under the supervision of Prof. Behrendt (h2) and Prof. Trojahn (HSA) were approved.

https://www.h2.de/no_cache/en/home.html

# Anhalt University of Applied Sciences

Innovation, cosmopolitanism, creativity and culture are traditions of the Anhalt region to which the Anhalt University of Applied Sciences with its three campuses in Bernburg, Dessau and Köthen and its seven departments feels particularly committed. Therefore, since its foundation in 1991 the university feels responsible for making a significant contribution to the economic and social development of the region and the state of Saxony-Anhalt through its practice-oriented education and applied research. The bachelor's and master's degree programs at the various departments have one thing in common - in addition to imparting specialist knowledge, they prepare the 8.000 students of the Anhalt University of Applied Sciences, from whom 2.000 have an international background, for a successful start to their careers.

In May 2021, the extension of the right to award doctorates to universities of applied sciences in Saxony-Anhalt gave rise to the "Social, Health and Economic Sciences" doctoral centre at Anhalt University of Applied Sciences, which is a collaborative effort between Anhalt University of Applied Sciences and three other universities in the state.

The Chair of Business Administration, in particular Supply Chain Management, Operations Management and Digitization, situated at the Department of Economics at Anhalt University of Applied Sciences and headed by Prof. Dr.-Ing. Trojahn, deals with current developments along entire supply networks with regard to various thematic research focuses such as:

- Supply Chain Network Design, Planning & Operations
- Operations Research
- Process Optimization
- Digitalization and Logistics 4.0
- Resilience
- Sustainability

www.hs-anhalt.de

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