University of Zagreb
Faculty of Mechanical Engineering
and Naval Architecture

International Centre for Innovation
and Industrial Logistics

ICIL 2023

International Conference on Industrial Logistics
May 31 – June 02, 2023, Hotel Kolovare, Zadar, Croatia

Conference Proceedings

Co-organizers

University North

Croatian Association for PLM

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Editor's Foreword

It is with great pleasure that I present this publication, which contains the papers from the 15th International Conference on Industrial Logistics – ICIL 2023. The conference took place in Zadar, Croatia, from May 31st to June 2nd, 2023. It was organized by the *Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb*, and the *International Centre for Innovation and Industrial Logistics*, with co-organizing assistance from *University North* and the *Croatian Association for PLM*.

The *International Centre for Innovation and Industrial Logistics* (ICIIL) is a non-profit professional association that has been developing an integrated view of Industrial Logistics, as well as sharing and exchanging ideas and research results among students, researchers, academics, and industrialists. The *International Conference on Industrial Logistics* (ICIL) is the main means to achieve these objectives worldwide, having been held in France in 1993, Brazil in 1995, USA in 1997, Russia in 1999, Okinawa (Japan) in 2001, Finland in 2003, Uruguay in 2005, Lithuania in 2006, Israel in 2008, Brazil again in 2010, Croatia in 2012 and 2014, Poland in 2016, and Israel again in 2016. After an unplanned break due to the corona pandemic, the ICIIL board decided to select Croatia and the Faculty of Mechanical Engineering and Naval Architecture as the location and host of the ICIL conference in 2023 to resume the continuous organization of this logistics event.

The ICIL 2023 conference featured a multidisciplinary program that included original research results, developed concepts, ideas, and real-life case study examples as contributions to the fields of logistics and supply chain management. The focus was on understanding and finding solutions to the ever-evolving logistics challenges in the world. Submissions for the conference came from 12 countries, further confirming this conference as an international meeting place to share and exchange ideas and results, as well as to establish new contacts and explore new possibilities.

Moreover, by sharing invited lecturers with the partner conference *Management of Technology Step to Sustainable Production – MOTSP 2023*, the ICIL conference highlighted the interconnectedness of logistics/supply chain management with innovation and sustainability.

Chairman's Welcome Message to Participants

On behalf of the international and local organizing committees, I would like to extend my warmest wishes to each one of you for a successful meeting. I believe this gathering will foster fruitful discussions, the exchange of experiences and ideas, and facilitate networking for further developments in the field of logistics on an international scale.

Prof. Goran Đukić, PhD

University of Zagreb
Faculty of Mechanical Engineering and Naval Architecture
Zagreb, Croatia

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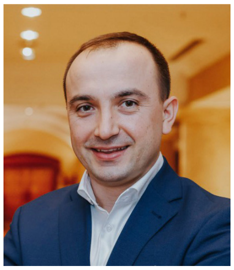
Invited Speakers

Matija Hoić

Matija Hoić is an assistant professor at the Faculty of Mechanical Engineering and Naval Architecture of the University of Zagreb. He received his Ph.D. in mechanical engineering from the University of Zagreb in 2015 and became an assistant professor in 2018. His research interests include mathematical modeling of dry clutch dynamics, design of mechanical components of electromechanical systems with an emphasis on the design of experimental setups for parameterization and validation of developed models, experimental identification and modelling of wear and friction factor of dry coupling friction materials, and innovation of the operating mechanisms of transport devices. He cooperated on several industrial research projects funded by Ford Motor Company, as well as a couple of EU funded projects. He is the author or co-author of 36 publications in refereed journals and conference proceedings.

Role of Mechanical Engineering in the Development of the European Fusion Project

European countries decided to reach energy independence through two groups of power sources. The first group includes renewable sources such as wind and solar which have already been greatly implemented. The other group includes a new generation of nuclear powerplants which are based on nuclear fusion process instead of the more conventional nuclear fission. The goal is to develop the first fully functional demonstrative nuclear power plant (DEMO), which will generate electricity at a commercially viable price. To successfully build and operate such a powerplant, two major sets of know-howe must be acquired in addition to existing knowledge gained from the current fission bases nuclear powerplants. The first set relates to generation, handling, and usage of plasma on a large scale by means of dynamic electromagnetic fields. Successful construction of ITER (International Thermonuclear Experimental Reactor) will provide the possibility of development of such technologies. The second set relates to the operational characteristics and degradation of materials which are influenced by long-term high intensity neutron radiation. Hence, a facility which will enable exposure of various materials to neutron radiation is planned, named International Fusion Materials Irradiation Facility – Demo Oriented Neutron Source (IFMIF-DONES). Within DONES plant project, several pieces of equipment are to be supplied by Croatia, with the largest two being cranes. These include Heavy Rope Overhead Crane (HROC) whose goal is to lift the cover of the test cell and the Access Cell Mast Crane (ACMC) whose role is to replace the sample and maintain the equipment within the test cell.



Miro Hegedić

Miro Hegedić received his Master and PhD in Industrial Engineering and Management at the University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture (FMENA). He is currently working as assistant professor at the Department of Industrial Engineering at FMENA. His main research interests are production and project management, process optimization and innovation and entrepreneurship. He has been active member of several EU funded projects working on developing new innovative products. Currently he is leading several EU funded projects and is coordinator of the EIT Manufacturing HUB Croatia. He is the author or co-author of 34 publications in refereed journals and conference proceedings.

Deep Tech Ecosystem for Manufacturing and the Role of TLFs

This presentation explores the deep tech ecosystem in manufacturing, emphasizing the importance of collaboration, innovation, and education in driving growth within the sector. It begins with an overview of deep tech and its components, discussing the key players in the ecosystem, such as industries, educational and research institutions, governments, and investors. The significance of innovation within the triple-helix model is examined, as well as collaboration between Regional Innovation System (RIS) countries and more developed European Union countries, informed by the EU innovation scorecard.

The presentation then delves into specific projects aimed at fostering innovation and competence development in manufacturing, with a focus on South-East Europe. The EIT Manufacturing HUB Croatia and its flagship project, the Manufacturing Innovation Challenge, are discussed as examples of initiatives aimed at boosting innovation in the region. The hybrid training course "CompetenSEE" and the project "Connect SEE" are highlighted as examples of initiatives that create state-of-the-art teaching and learning materials for the manufacturing sector and establish a network of Teaching and Learning Factories across South-East Europe. Furthermore, the lecture examines two projects demonstrating the triple-helix model's effectiveness in fostering innovation and collaboration. The development of a modular expert system for managing discrete production processes based on the application of Smart Factory principles and the creation of a high-efficiency solid fuel heating system from renewable energy sources using innovative technological processes are explored as examples of successful collaboration between industry, academia, and government, with the Faculty of Mechanical Engineering and Naval Architecture as a project partner.

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Conference Papers

OBJECT DETECTION AND GRASPABILITY ANALYSIS FOR ROBOTIC BIN-PICKING APPLICATION IN INTRALOGISTICS

Primož BENCAK, Darko HERCOG, Tone LERHER

Abstract: Robotics has been gaining attention in intralogistics applications in recent years. Automation of intralogistics processes aims to cope with the rising trends of workforce deficiency, aging, and increasing demands that came with the rise of E-commerce. Many improvements aim at bin-picking applications since order-picking requires most contributions while adding little to the products' value. Robotic bin-pickers are showing promising results; however, they are still subject to many limitations. First, the vision system must correctly determine the object's location and orientation. Second, a correct robotic gripper must be chosen. Lastly, appropriate grasping points that lead to successful picking must be selected. In this paper, we explore the influencing parameters of object detection using a 3D vision system. Second, we analyze an actual bin-picking application to determine the most appropriate selection of the robotic gripper. Based on the experiments, we provide the guidelines for selecting the most appropriate robotic bin-picking configuration.

Keywords: intralogistics, robotic bin-picking, detection analysis, graspability analysis

1 INTRODUCTION

Robotic order-picking is the subject of an increasing number of papers in the scientific community. Due to the rapid technological advancement, there is a strive towards implementing automation, especially collaborative robots, into the order-picking process [1]. Generally, European warehousing companies have issues with workforce deficiency and the aging population. The order-picking process, which relates to picking products according to the order, adds little to the product's final values yet requires substantial input [2]. The trends in intralogistics are heading in multiple directions regarding the automation of the order-picking process. In manual warehouses, order-pickers can be accompanied by AGVs or AMRs. Order-picker only retrieves products from the shelves, while the AGVs or AMRs provide the transport [3]. Further, AMRs can be equipped with a robotic arm to retrieve the products from the shelves instead of a human order-picker [4]. In automated warehouses, where products are stored in AS/RS, SBS/RS, or other automated warehousing solutions, there can be robotic order-picker stations, where products are moved on the conveyor belt towards the robotic order-picker. The entire order-picking process can be, therefore, automated.

The benefits of robotic order-pickers are primarily in the form of 24/7 operation since they usually cannot achieve as high picks-per-hour as the human order-picker. Robotic-order pickers can provide fully automated warehousing solutions in fully automated Micro and Nano Warehouses [5]. Still, for the robotic order-picker to work reliably, numerous studies must be executed beforehand due to the process's complexity.

Robotic order-picking generally consists of three major stages: a) object detection, b) grasp detection, and c) manipulation. To successfully perform order-picking, all three steps must be executed appropriately. In practice, there is still a lack of work that would deal with robotic order-picking as a whole.

Therefore, a set of procedures and methodologies must be developed to select components for the robotic bin-pickers. First, objects which can be bin-picked using a robot must be determined. Next, component limitations must be established. This paper provides a practical approach to designing a robust robotic order-picking operator. To elaborate on developing a practical approach for selecting the most appropriate components for the robotic bin picking, we have set the following research questions:

RQ1 – What factors influence object detection using a robot's 3D camera?

RQ2 – How to verify that selected objects are appropriate for robotic bin-picking?

RQ3 – How can the most appropriate robotic gripper be selected considering robotic grippers and 3D camera limitations?

Based on the results obtained from the actual robotic order-picking station, we propose a set of procedures and recommendations to determine the viability and feasibility of automating the order-picking process. From the results obtained, benchmark development is possible.

2 A BRIEF LITERATURE OVERVIEW

The robotic community is actively researching efficient methods and protocols (benchmarks) designed to evaluate and compare various robotic setups [6]. Those can be used to select the most appropriate robotic workstation for the desired task. However, those benchmarks are usually oriented toward robotic assembly [7, 8] or other manipulation tasks [9] not associated with robotic bin-picking. Further, researchers typically focus on a specific aspect of the robotic bin-picking process rather than at the system level, such as object detection (robotic camera detection algorithms), grasp detection (grasp predictors), and manipulation (robotic grippers [10-12]). Also, those benchmarks can be heavily complicated for an average user to be performed, limiting their potential value for time-limited (industry) users. Therefore, a simple, practical approach is needed to properly evaluate a robotic workstation's feasibility and operability, which can be easily reproduced.

Bin-picking applications also differ on a set of used objects and complex conditions, such as object occlusion. To provide fair benchmarking conditions for bin-picking applications, a YCB set has been proposed by Calli, et al. [13]. Based on the YCB object set, further, EGAD! [14] has been developed. Those object sets are used to compare various bin-picking metrics, such as the speed of the bin-picking application, robotic manipulator dexterity, grasp planning algorithms, etc. A more general benchmark for robot bin-picking has been proposed by Morgan, et al. [15]. The authors proposed a robotized version of the popular Box and Blocks Test to compare the robot's performance vs human order picker. A short review reveals that much work is still to be done, despite the highly interesting topic. The most obvious research gap is in the form of the absence of works that deal with robotic order-picking on the interconnecting component level.

3 ROBOTIC ORDER-PICKING

Robotic order-picking requires the precise and coordinated behavior of all its subsystems – the robotic arm (manipulator), machine vision system, and the robotic end effector (i.e., gripper). Since the robotic order-picking is fully automated, the location and orientation of the objects (products) must be derived from the machine vision system. The products are usually placed into bins in robot order-picking, associated with intralogistics; hence, bin-picking is generally used. The process is called random bin-picking if two or more objects are randomly placed in the same bin. The robot order-picking process can be divided into three stages: a) object detection, b) grasp detection, and c) manipulation, which are discussed in more detail.

3.1 Object detection

Object detection is the most critical phase in the order-picking process. Without precise information on an object's location and orientation, the rest of the order-picking process cannot be executed appropriately. In the bin-picking process, the machine vision system must be capable of providing the object's location and orientation. Therefore, 3D cameras are necessary. Usually, those cameras operate in infrared light specter, which makes them resistant to various light conditions. However, this is not the case with color detection since constant ambient lighting conditions are required. 3D machine vision systems can operate on multiple principles [16]: (1) stereo vision, (2) active stereo, (3) laser, (4) structured light, (5) time of flight, (6) time-coded structured light, and others. The most advanced cameras to date operate on the principle of time-coded structured light, which means that the interference pattern is changed during the detection process. The interference pattern is then scanned with the camera, and the pattern deviations are processed to retrieve the point cloud of the scene [17]. The camera can be robot-mounted or placed on a special camera mount. The robot-mounted camera has the advantage of adjusting the location and orientation, which can, in turn, increase the field-of-view (FOV) and detection area. However, it can contribute significantly to the robot's increased weight and reduced payload. Further, additional care must be considered when manipulating the robot to avoid camera damage. On the contrary, a separately mounted camera is more limited regarding camera positioning but can reduce the potential damage in the event of improper manipulation.

3.2 Grasp detection

Grasp detection is critical to ensure the object is picked in the correct zone. Grasp detection is the process of determining the correct pick-point(s) to provide successful grasping of the object. The grasp detection is robotics gripper dependent. Usually, two-fingered and soft grippers require pick-point pairs, while vacuum grippers with a single suction cup require only a single grasping point. Grasp detection can occur offline (before bin-picking) or online (during bin-picking) [18]. In offline grasp detection, the pre-determined (offline) grasp point is searched for on the object. In an online type of grasp detection, the process occurs directly before the bin-picking on the object to be picked without prior knowledge of where precisely the pick-point should be.

Lately, online grasp point detection methods are based on various deep-learning techniques, more reviewed in detail by [19]. Alternatively, grasp point detection can take place via learning-based methods, which are used to localize robotic grasp configurations directly from sensor data [20]. However, offline technics utilizing analytical and deterministic approaches are also viable if the bin-picking objects are known before the bin-picking operations [21]. Nevertheless, the pick-point must be selected or determined as robustly as possible. This means that small perturbations, which can arise from the machine vision system imperfections, should have as low an effect on manipulation as possible.

3.3 Manipulation

Different objects require various robotic grippers to be appropriately grasped. According to Schneider & Company [22], vacuum grippers are today's most used robotic grippers in industry settings. Collaborative robots usually employ (electric) fingered grippers since they do not utilize additional components. New technologies have enabled soft grippers [23], typically two-fingered by design but usually operated using a vacuum control unit. In the event of a bin-picking process, usually, some gripper extension is required. Otherwise, there might come a collision between the robot (gripper) and the bin.

4 METHODOLOGY

A sample robot order-picking workstation setup has been chosen to evaluate the selected object candidates for the robotic order-picking in various manners. The results obtained on the actual system are generalized to the extent that they could be used on arbitrary objects and arbitrary order-picking setups. Still, there may be some limitations to the applicability of the proposed recommendations, which can arise in the event of using vastly different order-picking configurations.

A UR5e collaborative robot arm was used in the setup. Three grippers were used for the experiments: a) two-fingered gripper "FT-85" by Robotiq, b) vacuum gripper "EPick" from Robotiq and c) soft gripper "mGrip P2" by Soft Robotics. For the vacuum gripper, three sizes of suction cups were used, d_1 = 12 mm, d_2 = 22 mm and d_3 = 30 mm. The suction cups are made from TempFlex HT material. The 3D vision system used is Pickit 3D M Education Kit.

A short overview of the gripper's specification is presented in Table 1. Table 2 shows the hardware used in the experiments.

Table 1 Robotic arm UR5e with the 3D camera and the three grippers used in the experiments

Robotiq FT-85 [24]	*Robotiq EPick [25]*	*Soft Robotics mGrip P2 [26]*
Stroke width: 0–85 mm	**Max. airflow:** 12 L/min	**Stroke width (adjustable):** 20–100 mm
Grasping force: 20–235 N	**Compressed air source:** Internal vacuum pump	**Compressed air source:** External vacuum pump
Closing speed: 20–150 mm/s	**Payload:** 0–16 kg (4 kg per suction cup)	**Payload:** 3,4 kg
Weight: 925 g	**Weight:** 710 g	**Weight:** 270 g

Table 2 Robotic arm UR5e with the 3D camera and the three grippers used in the experiments

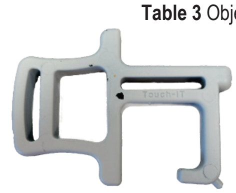
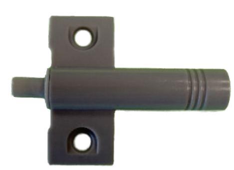
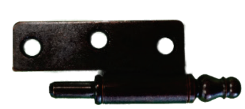
The experiments have been three-fold and conducted on several different objects. The main goal of the subsequent tests is to find the appropriate methodology to evaluate: (a) the possible object candidates for the detection, (b) the most appropriate camera placement, and (c) evaluate the appropriate gripper and configuration for the selected objects.

4.1 Object candidates for bin-picking application

The first test was conducted to determine possible objects that can be detected using the Pickit 3D M Education Kit camera under different camera positions. The general recommendations from the camera provider are that the objects are larger than (50 x 50 x 10) mm, have non-reflective surfaces, and are not entirely black or transparent. Darker colors and transparency absorb or reflect the interference pattern, interfering with detection. Additionally, camera location and orientation influence object detection; therefore, those parameters should be thoroughly studied to find the most appropriate camera position.

Based on the provider's recommendations, we have selected four objects (Table 3) to be thoroughly tested on various camera heights and rotations to find a) possible object for bin-picking application and b) determine the influence of camera position on object detection.

Table 3 Object candidates for the first test

	Hygienic door opener Object dimensions (mm): 81,9 x 60,8 x 9,1 Material: plastics Color: white
	Door hinge Object dimensions (mm): 36,1 x 101,5 x 40,4 Material: metal Color: gold
	Slow close mechanism Object dimensions (mm): 46,0 x 64,1 x 14,0 Material: plastics Color: gray mat
	Smaller door hinge Object dimension (mm): 24,4 x 65,8 x 8,7 Material: metal Color: patinated metal

The objects have been 3D scanned and imported into the Pickit 3D application, simplifying and improving the detection process. The detection parameters were left to the default values.

The test began with the different placements of the object on the green-colored pad (27 x 27) cm, divided into nine fields, which correspond to possible object positions (9 x 9) cm. Individual objects' orientation was changed at a 45° step, from 0° to 315°. The object was initially placed on the pad on its base surface to ensure the object's stability. Therefore, 72 data points (nine positions with eight orientations on each), each with five detections (altogether 360 data entries), have been collected. Only a single rotation axis was considered in this experiment since analyzing huge amounts of data manually proved to be very time-consuming. Since the objects in bin-picking are oriented randomly in the bin, experiments should be carried out by varying all three rotational axes. Therefore, further studies will focus on automating robotic arm movements and automatically analyzing and plotting data.

Figure 1 explains the analysis of measurements. Each larger field (bordered by a thicker line) represents one of the nine possible positions, and each of the nine squares within that field shows the object's orientation, which is rotated by a 45° step in a clockwise direction. Colors indicate the number of successful detections (red = 0/5, green = 5/5), and the number (e.g., 92.7) shows the average percent of detection score of all recognized objects in five detections.

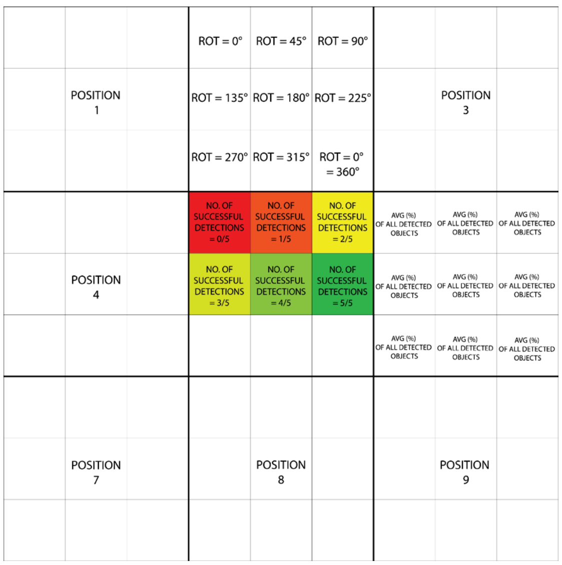


Figure 1 Explanation of object detection scores

The robotic arm with the camera mounted was first moved to the initial height of h = 45 cm. The object detection process was run for five times, with about five seconds between individual detections. Five detections have been run to replicate real-world bin-picking scenario – if no object is found on the first attempt, four other attempts are made before bin-picking processes is stopped. Also, we found that the detection score between the attempts tends to variate, therefore, multiple detections are made to account for these variations. Since the process of saving detection data is manual at this stage, there is a five second delay between each of the detections.

After each detection, we saved a screenshot of the current camera view, successful detections, and percentage of detection score. Afterward, we changed the object's orientation and repeated the process at new heights until we passed the measurements on all positions and orientations. The data was analyzed manually, and each position had to be written from the table to the Excel file from which it was saved in CSV format. The graphs were plotted in Adobe Illustrator, which allows for linking the generated variables with a CSV file.

4.2 Suitability of the robotic gripper

In the second test, new objects were selected for the bin-picking experiment (Figures 3, 4 and 5). The objects were selected according to the results of possible object candidates, outlined in Section 4.1 and camera manufacturer recommendations. In this experiment, a setup replicates the actual bin-picking application. Additionally, to using the last robotic bin-picking station, two bins of different dimensions and materials were added for the objects used (Figure 2).

The first bin is smaller (315 x 225 x 45) mm and made of cardboard, and the robotic order-picker requires no additional hardware since the camera and the gripper are far from the box's edges. However, the first bin has limited capacity, and it is therefore advised to use a bigger, plastic bin (400 x 300 x 120) mm for the actual bin-picking application. The original robotic grippers must be extended to avoid bin or camera collision. In the event of a vacuum gripper, we have extended the air outlet by using an aluminum rod with internal thread. The most critical part is to ensure the sealing of both ends. Otherwise, the lifting capabilities of the vacuum gripper expressively decrease.

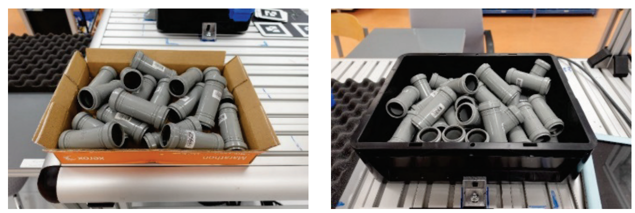


Figure 2 Bins used in the second test

This test aims to find the most appropriate robotic gripper from the selection for the sample bin-picking configuration and reveal possible gripper shortcomings in various scenarios. The robotic order-picker must successfully transfer the objects from the bin to the drop-off point, which is an arbitrary point (but the same for every experiment) located outside both boxes. For each part transferred, the gripper is awarded a single point. Since the grippers had different TCP (Tool Center Point) settings, the time results could not be directly compared.

The test ran under the following scenarios (Figure 3):

- the objects are first placed in an organized structure in the bin, laying on various objects' sides;
- the objects are placed in a way that the markings or any other features of the objects are orientated toward the robot;
- the objects are randomly oriented in the bin but organized;
- the objects are entirely randomly put into the bin.

Figure 3 Proposed scenarios for the robotic gripper evaluation

Sometimes, the objects in various configurations cannot be successfully detected. However, determining such border cases is critical in determining overall bin-picking success. It is also advisable to define as many grasp points as possible since this distinctly increases the number of successful picks.

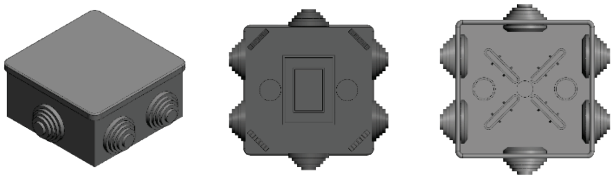


Figure 4 Junction box 3D object model

Next, object grasp points must be assigned according to the type of gripper used. In the case of PVC fitting, grasp-point pairs for two-fingered grippers are intuitively assigned. In the event of the junction box (Figure 4), those two objects are too wide for the limited stroke width of the two-fingered (s_1 = 85 mm) and soft gripper (s_2 = 70 mm). Therefore, they cannot be bin-picked using these grippers. The vacuum gripper requires that the contact surfaces are without any imprints or markings, which may pose a problem due to air losses on the edges of the suction cup. Therefore, the grasp points for the vacuum gripper should be placed only on flat or gently rounded surfaces without markings. However, we purposely selected points that could pose issues for the experiment. We have chosen various markings to determine the most appropriate size of the suction cup (Figure 5).

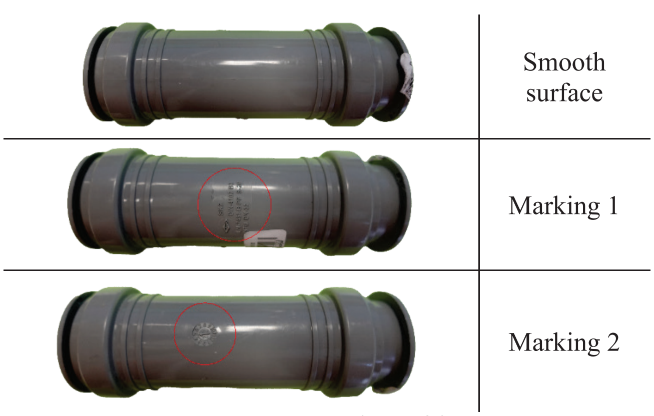


Figure 5 The markings of the PVC fittings

Next, since the soft gripper does not require additional electronics on the robotic wrist, only a simple extension has been designed. Lastly, in the case of a two-fingered robotic gripper, longer and thinner aluminum fingers (Figure 6) were used without additional modifications since the robotic gripper requires an electrical connection on the robot wrist.

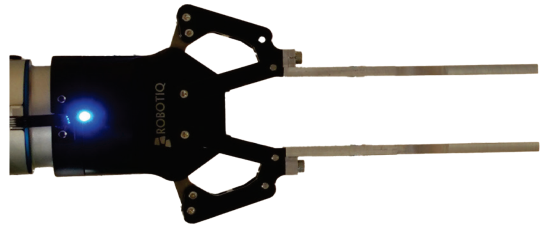


Figure 6 Extended fingers (*l* = 173 mm) for the 2F gripper

5 RESULTS

This chapter discusses the results obtained from the above experiments.

5.1 Object candidates for bin-picking application

Based on the results obtained from the first experiment, Figure 7 shows the results for testing the proposed object presented in Table 3. The camera has been positioned 45 cm and 50 cm from the base surface with a base angle of about 5°. As seen in Figure 7, some spots correspond to object position/orientation configuration in which object detection works less accurately. This part may be problematic for the detection in some configurations since a small metal part sticks out of the base surface of the object. As parts of the tested object are occluded in some configurations, the 3D camera receives only a portion of the entire object point cloud required for the detection process. In addition, there are visible differences between the two heights, even if there is only a 5 cm difference between the first and the second location placement.

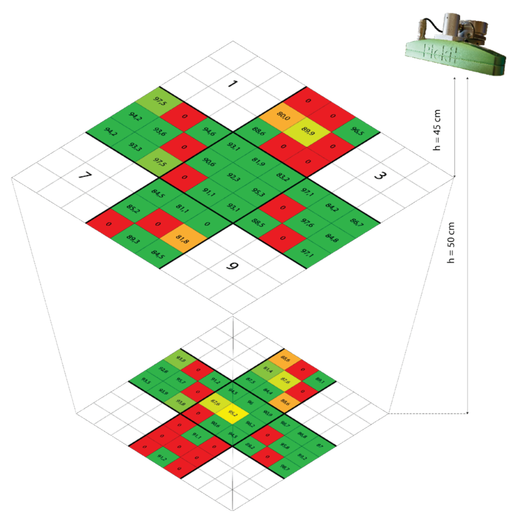


Figure 7 The results of object detection for door hinge (gold) in different positions for two camera heights

The overall detection rate for both positions tested of the hinged object is 64% for h = 45 cm and 63% for h = 50 cm. However, there are substantial differences between the two heights in position 2 and position 8 of the testing pad (Figure 7). For position 2, 39% for $h = 45$ cm and 67% for $h = 50$ cm are achieved. For position 8, 56% for $h = 45$ cm and 20% for $h = 50$ cm are accomplished. This indicates a relatively high chance that the object will be detected in positions 4-6 but a relatively low chance of detection in positions 2 and 8. The following also proves that the camera's height has a significant influence on the detection process.

Further, since object position/orientation impacts the detection process, this effect should be considered when performing the initial positioning of the bin or the robotic arm. Of course, a robotic bin-picker should be able to determine the object and its grasping points in various configurations since they are randomly put in the box. As with lower-resolution 3D cameras, that is not always possible. Since it is expected that there will be many objects in the bin, we can assume that even if only several objects are detected in an instance, the bin-picking application will work satisfactorily.

The experiments for other test objects have also been performed (Table 4). It was found that the first object (hygienic door opener) can also be successfully detected without any problems in any position and various camera heights. The second object (door hinge) is partially suitable for robotic bin-picking. It has a reflective surface and parts of the objects that stick out the base surface, which generates camera occlusion, preventing successful point-cloud generation. The third object (a slow close mechanism) is again successfully detected at heights (between 45 and 50 cm). Little differences exist between positions and object orientations, not affecting the overall detection process. Lastly, the small door hinge proved inappropriate for robotic bin-picking since it's very thin.

Table 4 Percentage of vision system detection score for a selected object at different heights and 5° camera rotation

Height/Part	**$h = 45$ cm**	**$h = 50$ cm**
Hygienic door opener	98.9%	99.1%
Door hinge	64.1%	63.0%
Slow close mechanism	97.6%	97.2%
Smaller door hinge	10.4%	14.6%

Based on the above findings, it can be concluded that the quality of detection depends heavily on several parameters (sorted from most to the least): convexity/concavity of the object, camera height, object material (surface reflectivity), object shape, object orientation, camera rotation, model parameters.

Therefore, performing experiments as proposed enables accurate evaluation of the most appropriate camera position, leading to higher detections. However, the process should be automated since the procedure requires substantial work due to manual data processing. Pickit 3D provides a ROS interface, enabling the detection process via Python script. This allows the automation of detection procedures and will be the work of future studies.

5.2 Suitability of the robotic gripper

The second (Gripper Suitability) experiment was first executed on the PVC fitting with the vacuum gripper and various suction cup diameters placed in a small bin. Table 5 shows the grasp success for multiple scenarios. Randomly oriented refers to objects that are placed in the box in an organized fashion, but the orientation is set randomly. However, "entirely randomly" refers to objects that are not placed in the box in an organized manner.

Table 5 Percentage of grasp success for junction boxes ($n = 14$) using vacuum gripper in a smaller bin with different suction cup sizes

Suction cup diameter/scenario	$d = 12$ mm	$d = 22$ mm	$d = 30$ mm
Smooth surface	100%	100%	100%
Marking 1	14%	0%	0%
Marking 2	100%	86%	93%
Randomly oriented	86%	86%	71%
Entirely randomly	93%	50%	86%

As can be seen from the results presented in Table 5, all vacuum suction cup diameters achieved a 100% success rate in the first scenario of the test (smooth surface). If the vacuum suction cup tries to pick the object on Marking 2 (Figure 5), only a suction cup with $d = 12$ mm proved successful in two cases. The suction cup with a diameter of $d = 22$ mm had the most problems in grasping with Marking 1. When the items were randomly oriented but placed in a bin, we achieved a success rate of 71% and 86% of all cases. It should be noted that success depends mainly on the number of cases in which the suction cup hits the markings. In the last scenario, the suction cup with diameter $d = 12$ mm had a 93% success rate, compared to 50% for the suction cup with $d = 22$ mm. It can be concluded that, in all cases, the gripper with suction cup diameter $d = 12$ mm had the highest performance and is, therefore, the most suitable for picking PVC fittings in smaller bins.

We tested the junction box object in the second part of the "Gripper Suitability" experiment (Figure 4). Only the operation of the whole system in the bigger plastic bin has been tested. As the possible grasping surfaces for the vacuum gripper are slightly smaller in this case, the experiment has been limited to two suction cup sizes, $d = 12$ mm and $d = 22$ mm. The selected grasp points are shown in Figure 8.

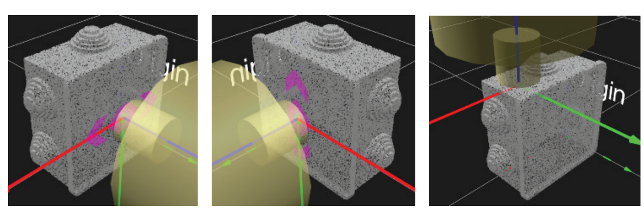


Figure 8 Selected grasp points for junction box

Additionally, the robotic gripper extensions have been used again. The results are shown in Table 6.

Table 6 Percentage of grasp success for junction boxes (n = 24) using vacuum gripper in bigger bin with different suction cup sizes (three attempts)

Suction cup diameter/attempt	d = 12 mm	d = 22 mm
Attempt No. 1	17%	71%
Attempt No. 2	13%	75%
Attempt No. 3	13%	50%

The results show that in the case of a suction cup size diameter d = 22 mm, the vacuum gripper is successful from 50% to 75% of all cases. The suction cup size diameter d = 12 mm gives inferior results (up to 17%). It can be concluded that a vacuum gripper is not the most suitable for this type of object, but in some instances, it may be the only option. Also, exact detection of the object is necessary, as even minor disturbances in detection can lead to a completely inappropriate grasp point and consequently to a failure in order picking. Next, the size of the suction cup itself must be selected very carefully.

It is worth noting that only smaller objects have been considered in this study, which are able to be picked up by a single vacuum suction cup. In practice, however, it is recommended to use several vacuum suction cups, which are more resistant to external forces and moments generated by robotic manipulator motion.

Lastly, a comparison between the three robotic grippers has been performed on PVC fittings in a bigger bin (Figure 9).

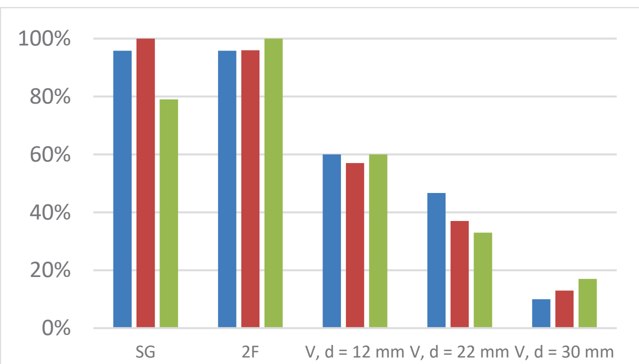


Figure 9 Grasping success for three grippers (SG = soft gripper, 2F = two-fingered gripper, V = vacuum gripper) for PVC fittings in a bigger bin. Colors indicate three separate runs of the experiment.

In the case of a larger bin (Figure 9), the two-finger gripper and the soft gripper have very high grasp success (up to 100%), with the vacuum gripper performing significantly worse (successful rate of up to 60%). Additionally, the results for the vacuum gripper, compared to the smaller bin, are now considerably worse. This may be due to the more expressive interactions between the objects – the PVC fittings have a very smooth surface. If they are randomly placed in the bin, small gripper movements cause the PVC fittings to slide, preventing the gripper from close contact between the suction cup and the PVC fittings.

Based on the results obtained with the vacuum robotic gripper, it can be concluded that it is suitable for flat and even slightly rounded objects. Special attention should be paid to tiny protrusions, production marks, or stickers present on the surface. The diameter of the suction cup is critical, especially when there are few grasping points. While the torque between the suction cup and the object is lower with larger suction cups due to the larger gripping surface, we are usually limited to smaller suction cups due to the surface features. Particular attention should be given to objects that are randomly placed on top of each other. The nature of the vacuum gripper can cause the grasping point to be displaced or missed altogether, as seen in the case of picking from a large box.

The results show that most appropriate robotic gripper setup for a selected application cannot be determined without extensive experiments. The process of robotic bin-picking leads us to the fact that many factors influence final application quality or performance. Even minimal differences in robotic bin-picker configurations, such as bin placement, camera height, gripper configuration, etc., can greatly impact the process. Therefore, a precise evaluation of the influencing factors must be determined with the help of various recommendations, benchmarks, and tests.

6 CONCLUSION

The performed experiments provide a practical insight into developing the robotic bin-picking application. The authors are aware of several shortcomings of the experiments since the data had to be collected and analyzed manually. Therefore, only a selected number of experiments were carried out. Experiments should be expanded to account for various robotic bin-picker setups, object sizes, camera rotations, etc. The basis of future work will take direction in automating object detection analysis.

The practical implications of this work are recommendations for selecting bin-picking components, designed to reduce the time for setup and testing purposes.

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Logistics 4.0: Challenges, Opportunities and Threats

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Climate change, the main accelerator of which has been consumerism and the industry driving it, soon will force companies to make changes that will intensify their activities in the natural environment. The Covid-19 pandemic, Due to their specificity, has disrupted global supply chains on an unprecedented scale. In addition, the progress of the analysis supported by the assumptions and tools of Industry 4.0 (I4.0) opens unlimited development opportunities. These changes also have a significant impact on Logistics, making the concept of Logistics 4.0 (L4.0) increasingly popular. The scope of defining L4.0 varies from the use of individual I4.0 tools to the presentation of complex models. This paper presents a literature review using the STAR method on the L4.0 concept to identify the scope of its determinants and possible perspectives for the development of logistics in the context of I4.0 and the challenges mentioned.

Keywords: *Industry 4.0, Logistics 4.0, STAR*

BUILDING A SIMULATION-BASED DISTRIBUTION SYSTEM WITH ELECTRIC FREIGHT VEHICLES

Predrag BRLEK, Konrad LEWCZUK, Patryk ŻUCHOWICZ, Fitim KURTI

Abstract: This article has emphasized the importance of using simulation models to address the challenges of urban freight distribution, particularly considering the growing concern about the environmental impact of transportation. By utilizing ICT and ITS to collect big data and leveraging powerful simulation software like FlexSim, we can create models that can accurately simulate truck movements and optimize costs while reducing fuel consumption and emissions. As technology and data collection continue to advance, we can expect simulation models to become increasingly effective in addressing these issues. This article highlights the importance of using system surveys and simulations to assess the impact of switching to electric vehicles in a delivery system. By gathering data, building a system model, developing a simulation model, and analyzing the results, we can gain insights into the differences in GHG emissions between fossil fuels powered vehicles and electric vehicles, as well as their impact on the delivery system's efficiency and cost. The availability of such information is critical in making informed decisions that consider both the environmental and economic impacts of adopting electric vehicles in the delivery system. Ultimately, this article provides valuable insights into developing sustainable solutions for the future of freight transport in urban areas.

Keywords: distribution, FlexSim simulation software, simulation models, sustainable urban logistics, urban freight, supply chain

1 INTRODUCTION

Globalization and supply chain management are two terms that are inextricably linked in today's world. Globalization is a process in which the world is becoming increasingly connected through trade, investment, and the movement of people. This process enabled the expansion of the market and the availability of products and opened the door to new business opportunities. Globalization has also led to increased competition and an increased need for faster, more efficient, and more reliable supply chains. Supply chain management has therefore become critical to global business.

1.1 Globalization and supply chain management

Supply chain management is the process of planning, organizing, executing, and controlling the activities required to obtain, transform, and deliver products or services from suppliers to end users. Supply chain management enables companies to manage their resources more efficiently, improve their competitiveness and meet the demands of their customers. Globalization has given companies access to new markets around the world, resulting in greater competition and pressure to reduce costs. In addition, globalization has allowed companies to find suppliers and manufacturers around the world, which has increased the complexity of supply chains. Companies that successfully manage supply chains in a globalized world need to be able to deal with these challenges. Companies need to work with suppliers, manufacturers, distributors, and other supply chain partners to ensure efficient deliveries in the right quantity, required quality, at the right time, and to the right place. This means that they have to find reliable suppliers and manufacturers, and they must be able to track the movement of goods in the supply chain in real time.

1.2 Sustainable supply chain management

Given the increase in global population and consumption, it is becoming increasingly important to ensure that products are produced and distributed sustainably. Sustainability refers to the ability to maintain economic, social, and ecological balance in the long term. Sustainability has become a key topic in business as consumers are increasingly aware of the importance of sustainability and choose products that are produced sustainably. Sustainability in supply chains includes the application of sustainability principles in all stages of the production, distribution, and use of products. This includes minimizing greenhouse gas emissions, using renewable energy sources, reducing waste, and using recyclable materials while promoting fair and ethical working conditions. Sustainability in supply chains can also have a positive impact on the economy, as it can lead to savings in energy and material costs, as well as improvements in product efficiency and quality. Therefore, companies that successfully integrate sustainability into their supply plans can gain a competitive advantage in the market.

1.3 City logistics aspect of the sustainable supply chain

An essential aspect of the supply chain that facilitates economic development and business opportunities, ensuring a smooth operation of large-scale freight transport activities in urban areas is city logistics (CL)[1]. The rapid increase in demand for urban distribution services, fuelled by e-commerce and urban consumption upgrading, has greatly burdened urban mobility, the environment, social welfare, and governance. It has resulted in significant challenges, from congestion, low accessibility, and inefficiency in mobility, through visual intrusion, greenhouse gas emission, and resource waste as environmental problems to noise and accidents in social life and land scarcity problem connected with urban freight transport for regulators in urban areas. The duality of city logistics has brought challenges to human health and quality of life. Among the many factors contributing to these problems, urban transport is a major culprit. Cities are at the forefront of suffering when it comes to issues like congestion, poor air quality, and noise exposure. Not only is city logistics costly, but it is also responsible for a large portion of air pollution emissions related to urban freight transport, estimated that between 16% and 50% of overall pollution from transport activities in a city can be attributed to urban freight transport. In fact, about a quarter of GHG emissions from transport can be attributed to urban transport alone. What's more, a staggering 69% of road accidents happen within cities) [2]. As cities continue to grow and develop, the importance of efficient and sustainable logistics becomes increasingly apparent. While often overlooked, the final link in the supply chain - city logistics - can represent a significant portion of the total transport cost, sometimes as much as 28%, according to a study by Roca-Riu and Estrada in 2012 [3]. To address these issues, it is necessary to develop sustainable solutions that can reduce the environmental impact of urban freight transport and relieve traffic congestion in city centers. This is particularly important given the continued growth of e-commerce and the increasing demand for last-mile delivery services [4].

1.4 Improving the sustainability of urban freight systems

The rise of e-commerce has led to a surge in home deliveries, which is increasing the social and environmental costs of goods distribution systems. To address these challenges, it is important to consider new solutions.

To combat these issues, the gradual phasing out of conventionally-fueled vehicles from urban environments is a crucial step. Reducing reliance on fossil fuels and decreasing greenhouse gas emissions and local air and noise pollution, can make cities more habitable and sustainable [2]. One potential solution to achieve this goal is by using low-energy and low-emission vehicles. Fortunately, there have been rapid advances in alternative fuel vehicles (AFVs) that have made it easier to achieve this goal. Some examples of AFVs include electric vehicles (EVs), hybrid vehicles (HVs), natural gas vehicles (NGVs), and fuel cell vehicles (FCVs). EVs are vehicles that rely on electricity from batteries for some or all of their driving energy. HVs, on the other hand, use two or more distinct power sources. In most cases, these vehicles combine a small electric battery with a traditional combustion engine. NGVs are another type of AFV that can run on either compressed natural gas (CNG) or liquefied natural gas (LNG). FCVs are another type of electric vehicle that generates electricity through an electrochemical process in the fuel cell stack [5].

Another approach is to encourage the consolidation of deliveries, whereby multiple orders are combined into a single delivery vehicle. This can help to reduce the number of vehicles on the road and improve overall efficiency [6]. Results of a study by Roca-Riu and Estrada in 2012 show the consolidation canter's benefits in the urban context, providing detailed metrics on costs, distance, and time. Additionally, they estimate the indirect savings on emissions and other environmental impacts [3].

Another approach is to encourage the use of alternative delivery methods such as bike couriers and cargo bikes. These modes of transport are not only environmentally friendly, but they can also be faster and more efficient in dense urban areas where traffic congestion is a significant issue. Furthermore, the use of cargo bikes can reduce the need for large delivery trucks, which can be difficult to maneuver in narrow city streets and contribute to congestion.

Finally, it is important to consider the role of urban planning in addressing the challenges of city logistics. By designing cities with logistics in mind, planners can help to create more efficient and sustainable transport systems. This could involve the creation of dedicated freight zones or the implementation of congestion charges for delivery vehicles during peak hours [7].

One possible solution for better planning and decision-making is to use simulation software to construct models of urban freight transport that are more sustainable and cost-effective. These models can help to better understand the impacts of different distribution systems and identify opportunities to optimize them for greater efficiency. Simulation software is a powerful tool that can provide insights into the specific status of a logistics system. By identifying bottlenecks and idle resources, simulation techniques can offer a detailed description of the actual process and information of the system, allowing for more informed decision-making and optimization [8]. For example, Flexsim simulation software is a powerful tool that combines advanced technologies such as 3-D image processing, simulation techniques, artificial intelligence, and data handling to help organizations optimize their operations. The software is specifically designed to cater to various industries, including production manufacturing, storage and delivery, transport systems, and more [9]. In this article, we'll take a closer look at what Flexsim software is and how it can be used to model and optimize complex logistics systems.

Ultimately, the key to improving the sustainability of urban freight systems is to take a holistic approach that considers a range of factors. By combining technology solutions with innovative delivery methods and sustainable urban planning, more efficient and sustainable systems that meet the needs of both businesses and consumers while also protecting the environment can be created.

Overall, sustainable city logistics is a critical component of urban development. By reducing transport costs, improving air quality, and relieving traffic congestion, cities can create more liveable environments that are better suited to the needs of their citizens.

2 MODEL BUILDING USING FLEXSIM SIMULATION SOFTWARE

Understanding the behavior of a system is crucial in a wide range of fields, including production, manufacturing, storage and delivery, transportation, and more. There are many methods available for studying and analyzing the behavior of a system, but the primary approach is to choose between studying the real system or studying the system via a model. While studying the real system is the most straightforward approach, it can be very time-consuming, intensive, and not feasible, particularly when most work with systems is focused on improvement or change, and the proposed system does not yet exist. This makes assessing the performance of system alternatives very difficult, and it is rarely effective to make a change and then assess the results. As a solution, modeling the system, especially using simulation software, becomes a better option. Models are abstractions of the real system that represent the features needed to assess performance. Simulation software provides users with a range of capabilities to help them simulate and optimize their systems. These capabilities include the ability to enter original data, build a system model, simulate the model, and analyze the results. This approach is particularly useful when analyzing complex systems and when designing new systems, making it a valuable tool in a variety of industries [9]. The software follows a basic modeling simulation process that includes surveying the system, collecting data, building the model, validating the model, simulating, and running the model, and analyzing the output optimization [8].

2.1 The system survey and simulated targets determination

The first step in the modeling simulation process is to survey the system and determine the simulated targets. This involves understanding the system and its components, identifying the key performance indicators (KPIs), and determining the goals of the simulation [9].

To achieve this goal, the company uses a typical routing strategy that involves dividing the service area into groups of points, determined by constraints such as time and capacity. Then, vehicle tours are designed within a given time horizon. The vehicles travel from the depot to a point within their service zone, serve the customers located in that zone, and then return to the depot. The process is repeated until all customers have been served, and the objective is to minimize the distance and time taken by the vehicles. This approach helps companies optimize their resources, reduce costs, and improve their overall efficiency. In the context of a delivery system, this would involve collecting data on the vehicles used, the delivery routes, and the drivers that are relevant factors for this particular case [8]. Once the data is collected, the next step is to determine the simulation targets. In this case, the simulation targets would be to assess the differences in GHG emissions between fossil fuels powered vehicles and electric vehicles, as well as to evaluate the impact of switching to electric vehicles on the delivery system's efficiency and cost.

2.2 The collection of simulation data

Once the targets are identified, the next step is to collect the basic data of the system. The collection of simulation data involves two aspects. Firstly, data is collected according to the established simulation goals to keep the system running normally. Secondly, the data involves starting conditions and internal variables of the system [8]. The starting conditions include the number of vehicles, the fuel consumption rate of each vehicle, the distance traveled by each vehicle, and the delivery routes. Internal variables of the system include the number of deliveries per vehicle, the number of stops made, and the time spent at each stop.

2.3 Building the system model

The third step is to build the system model. Once the data is collected, the next step is to build the system model. This involves defining the entities of the system accurately using a flow chart or network diagram [8]. The system model should accurately define the entities of the system, such as the vehicles, the delivery routes, and the drivers, using flow charts or network diagrams. The flow chart includes three parts: the arriving model of temporary entities, queuing discipline, and the model of service. The arriving model would define the frequency and timing of new entities entering the system, such as new parcels being received for delivery. The queuing discipline would define how entities are prioritized and processed, such as assigning a priority to urgent deliveries. The model of service would define the time it takes to process each entity, such as the time it takes to deliver a parcel or unload a vehicle.

To accurately assess the differences in GHG emissions between vehicles fossil fuels powered vehicles and electric vehicles, the system model would need to include data on the fuel consumption rate of each vehicle, the distance traveled by each vehicle, and the delivery routes [8]. Data collected on fuel consumption and calculated GHG emissions can be used to assess the environmental impact of the delivery system and to evaluate the potential benefits of switching to electric vehicles. This information can be used to make informed decisions about the best ways to reduce emissions and improve the sustainability of the delivery system. Internal variables of the system, such as the number of deliveries per vehicle, the number of stops made, and the time spent at each stop, would also need to be considered. This would allow for a comparison of the energy spending amount and GHG emissions for fossil fuels-powered vehicles versus electric vehicles.

2.4 Development of the simulation model

The fourth step is to build the simulation model. After the system model is built, the simulation model can be developed. The process includes confirming the storage form of the model and data and choosing software development platforms and program design languages based on the mathematical model and features of the system. The simulation model should be validated to determine whether it can accurately represent every part of the system [8]. In this article, we will discuss how to build a simulation model for city freight transport assuming a switch from fossil fuels consumption vehicles to electric ones. The approach consists of four main steps [6].

The first step is to generate instances of virtual city configurations. This involves describing the city, determining the number of delivery points, and configuring the road network, among other things. The use of this data has led to the development of powerful tools, such as FlexSim's GIS module, that can model various transportation use cases where travel time and distance are important factors.

The second step is to use FlexSim simulation software to build a feasible model that optimizes costs, energy consumption, and GHG emissions. The goal of this step is to find a solution that is close to the behavior of the drivers, rather than an optimal solution.

The third step is to assess the economic model by calculating the profitability of the tested solution. This step focuses on determining whether the proposed switch to electric vehicles is financially viable.

Finally, the fourth step involves identifying and proposing levers to improve the viability of the proposed solution. These may include changes to the delivery routes, the number of vehicles used, or the charging infrastructure [6]. By following this approach, we can create a simulation model that accurately reflects the behavior of drivers and the feasibility of switching to electric vehicles for city freight transport.

2.5 The simulation model validation and running phase

The fifth step is model validation, which involves determining whether the simulation model and computer language can accurately show every part of the system, including its composition, organization, and parameters. Once the simulation model is validated, the next step is to simulate and run the model. This phase is critical as it involves forecasting the actual moving principle of the system, which helps understand the output response with different inputs and simulation mechanisms. The output and analysis of simulation results will provide insights into the differences in GHG emissions between fossil fuel consumption vehicles and electric vehicles, as well as the impact of switching to electric vehicles on the delivery system's efficiency and cost. Based on the simulation results, informed decisions can be made regarding the adoption of electric vehicles in the delivery system, considering the environmental and economic impacts [8].

2.6 Analyse the output and results

Finally, the last step is to analyze the output and results of the simulation. This involves analysing the data and results to identify areas of improvement and opportunities for optimization. The results can also be used to validate and refine the model further. In conclusion, the use of system surveys and simulation is crucial in assessing the impact of switching to electric vehicles in a delivery system [8].

3 CASE STUDY MODEL USING FLEXSIM SIMULATION SOFTWARE

Flexsim software is a powerful tool that combines advanced technologies to help organizations optimize their operations. The software provides a range of capabilities that allow users to model and simulate complex systems, validate the model, and analyze the results. By following the basic modeling simulation process, organizations can leverage the power of Flexsim software to make data-driven decisions and optimize their systems for maximum efficiency and performance [9].

3.1 The case study system survey and simulated targets determination

Increasing focus on sustainability, reducing greenhouse gas (GHG) measured in carbon dioxide equivalent or CO2 equivalent, which is a metric measure used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), has become a top priority in today's world. One area where emissions can be reduced is the transportation sector, where the use of electric vehicles can significantly decrease GHG emissions compared to vehicles that run on fossil fuels such as oil [2]. However, assessing the impact of such a change on a delivery system requires a thorough understanding of the system, its components, and its interactions [10]. This is where system survey and simulation come into play. A system survey involves gathering data about the system, including its current state, its components, and its interactions. In this case, a company needs to serve an urban area in Warsaw, Poland, with several customers using vehicles that have some capacity, from a depot located at the service area. The area has defined customer density.

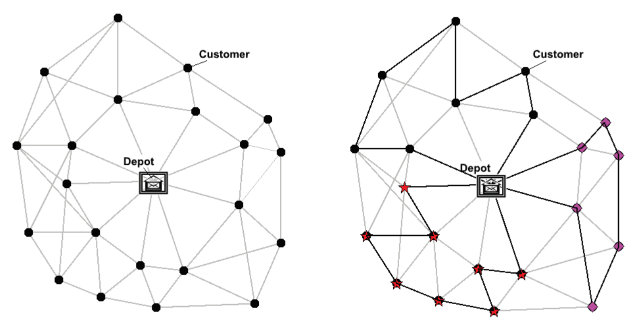

Figure 1 Network diagram

The main goal of the company is to design routes that minimize the weighted sum of distance costs and temporal costs, which means minimizing the distance travelled by vehicles while also minimizing the time they consume [3].

3.2 The collection of simulation data for case study

As we continue to experience the information revolution, there are both opportunities and challenges when it comes to improving the sustainability of urban freight systems. With the advancement of Information and Communication Technology (ICT) and Intelligent Transport Systems (ITS), it has become much easier to gather big data related to the movements of pickup-delivery trucks and goods in urban areas. On one hand, low-cost sensors can be used to automatically collect a range of vehicle movement data that can help us better understand distribution systems and increase their efficiency. This has been made possible using Global Positioning Systems (GPS) devices that are typically equipped in trucks. Trucks are usually equipped with GPS devices that provide precise location data every second, enabling efficient data collection at a lower cost. These devices allow for the precise measurement of the location of trucks every second, making it easier to track the routes of urban trucks. As a result, this data can be analyzed to gain insights into the movements of these vehicles and identify areas for improvement in terms of efficiency, safety, and environmental impact Monitoring technologies can also be used to charge both passenger and goods vehicles for using the road system, opening a range of new pricing schemes [5]. This data will be used to assess the differences in GHG emissions between fossil fuel consumption vehicles and electric vehicles in the cargo delivery system in Warsaw, Poland. Table 1 consists of data for 10 different routes for the specific delivery vehicle. The vehicle type, which was used in the case study, is Mercedes-Benz Sprinter Panel Van 311 CDI, 2019., diesel fuel powered. Here's a table that involves real collecting data.

Table 1 Collecting data in cargo delivery firm

Route ID	Number of Deliveries	Driving Time (hh:mm)	Stopping Time (hh:mm)	Distance (km)	Fuel Consumption (L)
R1	60	05:21	01:18	80	8.5
R2	75	05:53	01:32	65	7.0
R3	64	04:45	01:25	70	9.2
R4	71	05:02	01:41	75	8.0
R5	70	05:58	01:46	80	7.5
R6	65	04:23	01:30	65	8.5
R7	72	05:51	01:48	70	6.5
R8	61	05:37	01:09	75	9.0
R9	68	05:33	01:23	80	8.2
R10	70	05:14	01:39	70	6.8

In this table, Route ID represents the unique identifier for each delivery route, the Number of Deliveries represents the number of parcels delivered in a particular route, Driving Time is the time spent in driving mode from depot to each customer and back to depot measured in hours and minutes, Stopping Time is the time spending in delivering goods to the customer when the vehicle was not driving measured in hours and minutes. The Distance column represents the total distance travelled by each vehicle on each delivery route, while the Fuel Consumption column represents the amount of diesel fuel consumed by the vehicle during the delivery.

3.3 Building the case study system model

The system model for the Warsaw cargo delivery firm involves several entities, including vehicles, delivery routes, drivers, and parcels. A flow chart is used to define these entities accurately. Here is an example of a flow chart for the Warsaw cargo delivery firm.

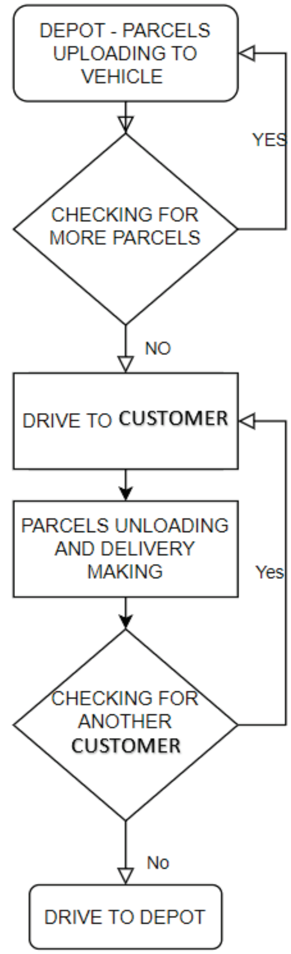

Figure 2 System model flow chart

The flow chart consists of three main parts: the arriving model of temporary entities, queuing discipline, and the model of service. The vehicles are the mode of transportation for the parcels, and they travel along the delivery routes to make deliveries to customers. The drivers are responsible for driving the vehicles and making the deliveries, while the parcels are the items being delivered.

The arriving model involves parcels arriving at the start of each day and being assigned to delivery routes.

The queuing discipline would define how entities are prioritized and processed. In the case of the cargo delivery firm, this would involve prioritizing deliveries based on their destination and urgency and ensuring that each delivery is assigned to the most appropriate vehicle and driver. The queuing discipline involves prioritizing urgent deliveries, such as medical supplies or perishable items.

The model of service involves the time it takes to deliver each parcel, which can be affected by factors such as traffic congestion or the time it takes to unload. The model of service would define the time it takes to process each entity. In this case, it would include the time it takes for a vehicle to travel along a delivery route, the time it takes for a driver to make a delivery and unload the parcel from the freight vehicle at each stop, and the time it takes for a vehicle to come back to the depot after last parcel is being delivered.

3.4 Development of the simulation model

After the system model is built, the simulation model is developed.

FlexSim's GIS module (see Figure 3) is used, because it can model various transportation use cases where travel time and distance are important factors.

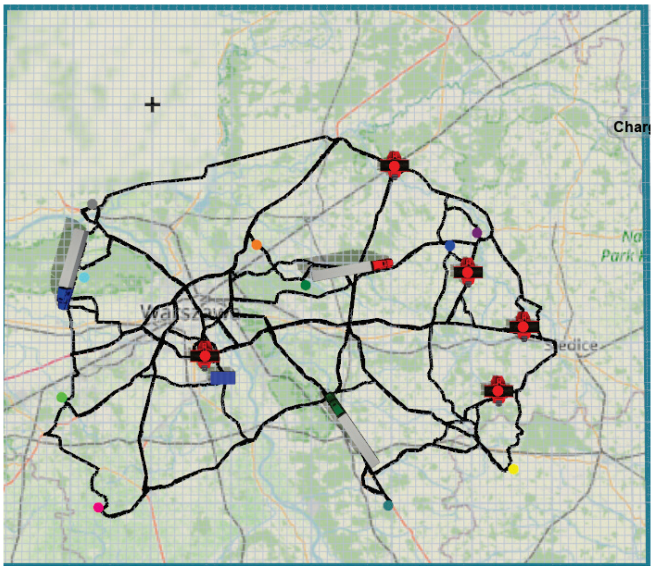

Figure 3 Simulation model for city freight transport

The GIS module is based on the new Map object, which can be easily accessed from the library and placed into the 3D View. Once the Map object is selected, users can pan the map's position and zoom in on specific locations using the mouse wheel. Points can be dragged onto the map, and their shapes can be customized to enhance visualization. Task Executors can be connected to these points to visualize the route, and the module also provides pre-installed vehicle shapes.

The GIS module supports three types of routes: Driving Roads, Flight Paths, and Custom Route Types. The Driving Roads route type downloads road information from the routing server, allowing road vehicles to take the shortest route between two connected points. This feature is pre-configured for convenience, making it easy to use for modeling transportation systems [11]. Given that all models are only approximations of real systems with a certain level of accuracy since not all real variables can be predicted and included in the model, the data from Table 1 were used to create empirical distributions that determine the behavior of certain objects in the model, such as movement speed or the duration of each delivery, which fits into the distribution curve of the behavior of a certain real object in the model. As with any other distribution, the behavior of a certain real object can hardly be accurately predicted, however, by creating an empirical distribution according to real data and applying it to the characteristics of the behavior of an individual object through a large number of iterations, reality can be better simulated. Using FlexSim simulation software, an accurate simulation model for city freight transport that optimizes costs, energy (fuel) consumption, and GHG emissions was built.

The goal of this step is to find a solution that is close to the behavior of the drivers, rather than an optimal solution.

3.5 The simulation model validation and running phase

The fifth step was model validation. It was tested if it is built well, including its composition, organization, and parameters in the Process Flow part of the simulation.

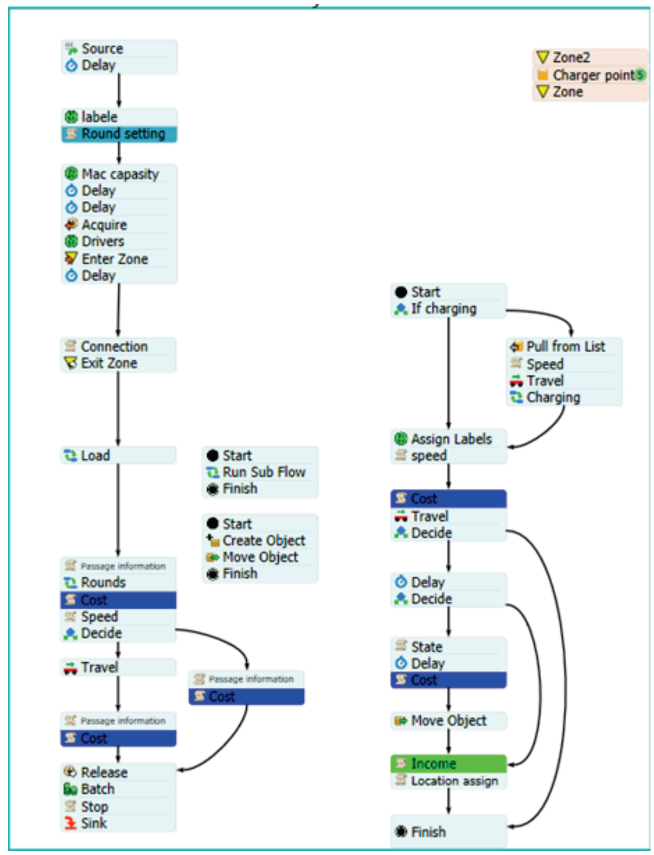

Figure 4 Process Flow part of the simulation

Using Process Flow the actual moving principle of the system, which helps understand the output response with different inputs and simulation mechanisms can be made [12]. The validation process involves comparing the output of the simulation model to the actual data obtained from the system to verify the accuracy of the model. Any discrepancies are addressed, and the model is refined until it accurately represents the real system. After validation, the model was running.

3.6 Analysis of the Results

Analysing the output and results of the simulation is the last step. Gathering data about the system, building a system model, developing a simulation model, and analyzing the simulation results provide insights into the differences in

GHG emissions between fossil fuel consumption vehicles and electric vehicles, as well as the impact on the delivery system's efficiency and cost. Greenhouse gases (GHGs) are gases that trap heat in the atmosphere and contribute to climate change. One of the most common GHG is Carbon dioxide (CO2) and others include methane (CH4), nitrous oxide (N2O), and fluorinated gases. GHG emissions are measured in units of carbon dioxide equivalents (CO2e), which represent the amount of CO2 that would have the same warming effect as the GHG being measured. Methodology for calculation and declaration of energy consumption and GHG emissions of transport services (freight and passengers) can be using EN16258 as a uniform standard for calculating greenhouse gas emissions for supply chains or using some online applications that are using that methodology. This information is critical in making informed decisions that consider both the environmental and economic impacts of adopting electric vehicles in the delivery system. By comparing the fuel consumption and GHG emissions of the vehicles, we can evaluate the environmental impact of the current delivery system and assess the potential benefits of switching to electric vehicles. Analyzing data outputs is an essential step in the simulation process, as it allows users to identify patterns, trends, and anomalies that can inform decision-making [9, 12, 13]. With FlexSim simulation software, users can easily study the data outputs generated by their simulation model and make changes to the model as needed. In addition, the software enables users to export data for analysis by third-party tools, further expanding the scope of analysis. FlexSim simulation software also offers advanced data-gathering tools, such as the Statistics Collector and Calculated Table, which can be used to transform raw data and gather additional insights [14]. By utilizing these tools, organizations can gain a more comprehensive understanding of their operations and make informed decisions that drive efficiency and cost savings. FlexSim simulation software offers a robust platform for simulation modeling and data analysis, making it an invaluable tool for businesses seeking to optimize their operations. The use of these tools can help organizations optimize their operations, reduce costs, and improve efficiency.

4 CONCLUSIONS

In conclusion, the use of simulation software such as Flexsim is an essential tool for analyzing complex systems, designing new systems, and optimizing the performance of existing systems. The modeling simulation process involves surveying the system, collecting data, building the system model, validating the model, simulating and running the model, and optimizing the system. The simulation involves running the model through a range of scenarios to evaluate the performance of the system. This allows the evaluation of the environmental impact of the delivery system under different conditions, such as varying the number of vehicles or the routes taken. The simulation software can then generate output reports and graphs, which can be used to analyze and evaluate the performance of the system under different scenarios. The output of the simulation is used to optimize the system. The simulation results provide insights into the performance of the system, allowing for the identification of areas for improvement. For example, the simulation might show that the use of electric vehicles can significantly reduce GHG emissions compared to fossil fuel consumption vehicles. This information can then be used to optimize the delivery system by replacing fossil fuel consumption vehicles with electric vehicles, reducing emissions, and improving the sustainability of the system. By using simulation software, companies can evaluate the impact of different scenarios, such as switching to electric vehicles, on the performance of the system, leading to more informed decision-making and improved sustainability. This article describes how to create a simulation model for monitoring fuel consumption and GHG emissions using FlexSim software on the example of a distribution company, and the model was created using real input data. This model can be used to compare the use of electric and diesel delivery vehicles in urban freight distribution in the Warsaw area. That will be part of the next article. The limitation of this model is that it is prepared for the specified location and the specified vehicle and routes. Given the individual characteristics of each individual case related to routes, types of vehicles, behavior and characteristics of individual drivers, traffic congestion, urban architecture, and urban logistics solutions related to delivery locations and package delivery locations, when creating such models, each project must be approached on its own peculiar way.

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Modelling Freight Allocation and Transportation Lead-Time

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The authors have investigated sustainable environment delivery systems and identified transportation lead-time investigation cases. This research study aimed to increase freight delivery lead-time and minimize distance in transportation. To reach the goal, the paper's authors, after analysis of the hierarchy of quantitative methods and models, proposed the framework for modeling freight allocation and transportation lead-time and delivered a study that includes discrete event simulation. During the simulation, various scenarios have been revised. Following the simulation mentioned above analysis, around 3.8 % of distance could be saved during freight delivery if lead-time for transportation were revised by choosing five days criteria for modeling freight allocation. The savings depend on the number of received orders from different geographic locations.

Keywords: *Freight transportation, delivery system, discrete event simulation, environmental sustainability, lead-time*

DETERMINANTS OF THE STRATEGY OF COMPANIES IN THE TRANSPORT INDUSTRY IN THE FACE OF ITS PROSPECTS FOR AUTONOMIZATION – HUMAN FACTOR PERSPECTIVES

Szymon NOWACZYK, Marcin BUTLEWSKI, Wiktoria CZERNECKA

Abstract: The article presents the determinants of the strategy of automation and autonomisation of means of transport in Poland. The research analysed the strategies that transport companies can use to leverage autonomous vehicles and more effectively achieve business goals. The paper presents the opportunities and risks associated with the prospect of developing autonomous transport in Poland, based on research in the form of in-depth interviews with experts involved in the management of transport companies providing their services in Poland. The study sought answers to the questions of when it will be possible to implement autonomous vehicles, to whom they will be a threat, and what benefits they can bring to transport companies. The result of the research is the determination of the conditions for the implementation of autonomous vehicles, their impact on the current development strategies of companies.

Keywords: autonomization, autonomous vehicles, development strategies, human factors, in-depth interviews

1 INTRODUCTION

1.1 Justification of the topic

Autonomous vehicles have the potential to be the answer to the challenges of modern transport. The emergence of autonomous driving systems coincides with the stabilisation of the car sales market after years of uninterrupted growth [1]. Autonomous transport can be one of the means to implement the European Union's sustainable development strategy, which has been planned for more than a decade [2]. The market for autonomous vehicles is becoming more accessible. Solutions are being offered that allow transport companies, such as passenger transport companies like Uber, to operate in new markets and develop new opportunities. The development of autonomous vehicles is made possible by the huge amount of funding going into the development of the technology, both for the vehicles themselves and the infrastructure, but it also requires the readiness and maturity of companies. [3]. Owners and managers of transport companies are beginning to see huge potential for the development of their businesses in the implementation of autonomous vehicle solutions. It is estimated that around 1.4 million vehicles with at least level 3 autonomy will be sold worldwide in 2019, with global sales of these vehicles reaching around 58 million units by 2030 [4]. Increasingly, driver-assistive driving technologies are becoming a factor in the purchase of transport vehicles [5][6]. An important prerequisite for the development and deployment of autonomous transport technologies is the result of an economic and safety analysis of the systems in view of the state of the factors modifying safety [7]. Despite these concerns, emerging evidence of the effectiveness of autonomous systems [8] will encourage companies to the deployment of modern and to some extent autonomous transport systems [9]. In order to grow, transport companies are expanding their fleets, conquering new markets, increasing their turnover and attracting new customers, in order to grow effectively, they implement strategies to do so more efficiently. Autonomous vehicles are a factor that can make the companies that deploy them first into the system to became cost leadership with reducing transport costs. The actions taken by transport companies are related to the desire to achieve a strategic advantage, which they can achieve by taking the lead in total transport costs. The reduction of costs resulting from accidents involving people is also an important factor. In Poland in 2021, in nearly 23 thousand accidents reported on public roads, 2245 people died and 26415 were injured. Accidents caused by fatigue, falling asleep alone accounted for 538 accidents (of which 92 were killed, 745 injured) [10]. Taking into account the unit cost of a fatality, €560,000, and the cost of a severely injured person over €770,000 [11], then autonomous transport can be an important factor in reducing the costs of road accidents caused by so called human factor.

1.2 Autonomation of transportation means and its scope

The term autonomy has long been used among the robotics and artificial intelligence community as a term used to describe systems that have the capacity and authority to make decisions autonomously. Over the time this term has been extended to represent the entire functionality of the system, not just as decision-making (other commonly used are: perception, decision-making and task execution)[12]. Use of the phrase in relation to a vehicle and calling it an autonomous vehicle refers to its communication and/or cooperation with an external operator or driver for information acquisition and data collection. Automation systems can be called autonomous systems if they perform their tasks independently and self-sufficiently. The time to implement autonomization depends on its level, which, according to the division created by the SAE organisation, can have 6 levels, from "No Driving Automation" to "Full Driving Automation". Other defined levels are:
Level 0: No Driving Automation
Level 1: Driver Assistance
Level 2: Partial Driving Automation

Level 3: Conditional Driving Automation
Level 4: High Driving Automation
Level 5: Full Driving Automation

These levels are not indicative of the extent of automation due to the fact that it can change. An autonomous vehicle (AV), as defined by the Society of Automotive Engineers, does not include a motor vehicle equipped 'only' with active safety or driver assistance systems. Instead, the autonomous vehicle mode in this context is able to sense its surroundings and move without human input or intervention. The autonomous vehicle combines output from various sensors to perceive its environment (e.g. Radar, LIDAR, SONAR, GPS, Odometry, inertial measurement units, etc.), all controlled by an on-board control system that: interprets the sensory information and identifies navigation paths, obstacles and relevant traffic signage [13]. A significant proportion of vehicle automation solutions will aim to assist drivers in managing the phenomena associated with sensory fatigue and the resulting reduction in driving ability. [14]. Many manufacturers are announcing the launch of a so called "game changer" - such as the Tesla Semi, which is said to have the potential to be for electric and autonomous trucks what the Tesla Model S was for electric-powered vehicles, that is, the first mass-produced vehicle in its class. which, thanks to its software, can support the driver in driving and, under certain conditions and with the control of the vehicle operator, can move autonomously [15].

1.3 Potential of autonomous transportation means and research hypotheses

While the prospects for change in the development of autonomous vehicles can happen almost overnight (as the situation of the GPT chat created by Open AI has shown), the financial dimension may indicate the momentum of the technology so far. It should be added that the potential for development is also linked to the legal regulations for automated vehicles, so that in Poland, for example, only vehicles of at most class 2 are allowed, bearing in mind, of course, that any damage caused by autonomous vehicles is the responsibility of the vehicle owner and the person supervising the control of the vehicle by the system. [16].

According to calculations made by the Stanford AI Index 2021 report, 'Autonomous vehicles' were one of the largest areas of investment in artificial intelligence research in 2020, with $4.4bn spent in the form of private investment [17]. The Boston Consulting Group estimates that the market for autonomous vehicles will reach $42 billion in 2025 and grow to $77 billion by 2035. They also forecast that vehicles with Level 3 and higher levels of automation will account for 25% of all new vehicles sold by 2035. According to McKinsey and Company, the global sensor market for ADAS (Advances Driver Assistance Systems) and AD (Autonomous Driving) systems will be worth $43 billion by 2030 [18]. The fastest growing segment is LiDAR sensors, which can scan an area in three dimensions and create high-resolution maps of the surrounding environment. It is estimated that autonomous vehicles have become a key research focus for the development of artificial intelligence. The global market for autonomous cars in 2021 was valued at more than $27 billion. The technology of fully autonomous vehicles is extremely complex. In the UK, it is forecast that 73% of all cars will have some level of autonomy (Level 1-3) before fully autonomous vehicles (Level 4-5) begin to enter the market, which is forecast for 2025 [19]. One of the main reasons for the prolonged wait for autonomous vehicles is the current legislation, which, especially in Poland, has not kept up with the technology; another reason is insufficient infrastructure, both road and communication. The infrastructure is not sufficient to allow autonomous cars to communicate with each other and collect information about driving conditions and traffic jams or potential obstacles blocking the road. Hence, the potential is seen in the use of partial systems - e.g. truck platooning - i.e. the combination of multiple units in the form of a train, where the first vehicle is driven by the driver/operator and the vehicles behind it mimic the driver's behaviour, braking speed, etc., and move behind the leading vehicle. [20]. The technology was expected to become widespread as early as 2022, but the potential to reduce costs by 10% of total TCO - total cost of operation - could be a significant motivator for its deployment in future years [21]. A model of such simplified autonomization nevertheless requires relatively elaborate decision-making schemes, where many modifying factors should be taken into account in the implementation of the scenario [22]. With even these still limited opportunities for autonomous vehicles in mind, it is forecast that sales of autonomous vehicles will increase fifteenfold between 2022 and 2030 [4].

Given such determinants of transportation automation, one can wonder about the factors leading to its spread, and in particular about the limiting values of parameters, the achievement of which will create a high probability of triggering a chain of dynamic changes in the field of autonomous transportation. Thus, the working hypothesis adopted is that the factors enabling the dynamic development of autonomous transport are mainly non-technical, socio-economic in nature.

2 METHOD

The study involved in-depth interviews with experts from the transport industry. The aim of the study is to identify the perceived opportunities and risks associated with the prospect of developing autonomous transport in order to identify the determinants of companies' strategy. The interviewees are experts from the field of transport companies, who are involved in the decision making process when running transport companies - which vehicle to choose, a standard truck or a partially autonomous vehicle?

Experts operating/representing companies of different sizes operating in Poland were selected for the survey. Individuals representing a variety of companies were selected for the survey. The respondents include representatives of sole proprietorships, small, medium and large companies. Expert 1 - Owner of a micro-enterprise in the transport sector, carrying out orders in the territory of Poland. The fleet he manages consists of 4 vehicles, tractor units with semi-trailers. The company operates on the domestic market and carries out transport orders for external entities. Expert 2 - President and owner of a medium-sized company in the transport and logistics sector. The fleet he manages includes 40 truck sets and 87 employees. The company he manages specialises in international land transport of goods and also provides a variety of logistics and freight forwarding services throughout the European Union, the UK and Switzerland. Expert 3 - Owner of a small business with approximately 25 own trucks. The company he represents carries out its services nationally and internationally, and as part of its activities the company provides bulk, full truckload and specialized transports. Expert 4 - Operations director at a large company with nearly 700 employees and 350 own truck sets. The company provides road transport and freight forwarding services, trade fair logistics, air and sea freight forwarding. Expert 5 - Manager of a logistics operator - a company engaged in the commissioning and supervision of transport and logistics services, dealing with cooperation with transport companies carrying out and commissioning transport of goods in all countries of the European Union, the United Kingdom and Switzerland.

During the open-ended interview, decision makers and their staff were asked about the factors that drive vehicle purchases and how the acquisition of new vehicles and advanced technologies affects their company's strategies. Five experts were invited to participate in the survey. The interviews were conducted in the form of an open-ended question and answer session, which allowed the structure of the experts' statements to be preserved, despite the fact that the interviewees sometimes made casual references to the questions asked. As a result of the research, statements were obtained that not only provide answers to the questions asked, but also allow us to get an opinion from the respondents and understand where their attitudes come from.

The survey asked 11 main questions, each of which was expanded upon as the interview progressed. The questions clarified three main categories: knowledge of autonomous vehicles and how to obtain it (questions 1-3), opportunities for autonomous vehicle deployment, determinants and prospects (questions 4-9), and whether autonomous vehicles fit into companies' growth strategy (questions 10-11). The questions were modelled on similar studies conducted by Abraham and his team and Stoma [5][6]. The questions asked were:

1. Are you satisfied with the driver assistance technology used in today's vehicles? Why? Which technologies could you single out?
2. Are you looking for information on new vehicle technologies? How do you obtain such information?
3. What must be the driving technologies that determine your decision to buy a particular tractor?
4. Will autonomization be important in the next 8 years for transport companies in Poland?
5. Are you willing to use alternatives to traditional road transport in the next 8 years? What would these alternatives be?
6. Please specify the circumstances that would contribute to autonomous vehicles becoming popular in enterprises in Poland in the next 8 years?
7. Please give any factors which indicate that autonomous vehicles will not become popular in businesses in Poland in the next 8 years?
8. Will autonomous vehicles present opportunities for the development of transport companies? If so, under what circumstances?
9. For whom in the transport industry in Poland will autonomous vehicles be a threat?
10. How much more would you be willing to pay for a vehicle if it was equipped with driver-assistive driving technologies?
11. Are autonomous vehicles part of the development strategy of companies you know?

The questions in the first group make it possible to determine the level of knowledge that transport management experts have about autonomous vehicles and how this knowledge is derived, so that it is possible to assess at what stage these companies are ready to deploy autonomous vehicles. The questions in the second category were designed to determine the timeframe the experts estimated for the wider implementation of autonomous vehicles in the companies they manage, but also in the transport market as a whole. Within this set of questions, the experts were also asked to identify the potential opportunities and threats they see in the deployment of autonomous vehicles. Crucially, from the point of view of research into business development strategies, the experts were asked whether autonomous vehicles fit into their company's development strategy and in what perspective these strategies fit into their company's strategy. In this context, the experts were also asked how much they could invest in business development as part of an investment in an autonomous vehicle system.

3 RESULTS

The results of the in-depth interviews conducted with the experts are the development strategies of the companies, where they have identified time frames for the implementation of autonomous vehicles in the companies they manage. Most of them believe that it will not be possible to implement autonomous vehicles in their companies in the next 8 years, but they also believe that this is the period in which they should undergo significant development and their implementation in their development strategies will be possible, and as early as 10 to 15 years, when they will start to be implemented in companies. The process of implementing autonomous vehicles in transport companies, although not present in the companies managed by the experts taking part in the survey, is ongoing.

The most frequently mentioned aspect related to the need to introduce autonomous vehicles is the huge shortage of drivers on the market. It is estimated that there is a shortage of around 100,000 drivers in Poland alone. Experts point out that there is an outflow of workers from the industry all the time. They note that the work of a driver is very demanding. Low-level autonomy would certainly make such a position easier, which could lead to an increase in interest among new employees ready to work in this industry. Experts therefore foresee a greater interest in vehicles that could carry out transport themselves. This would make up for the shortage of drivers. For the same reason, an important rationale for the use of autonomous vehicles - the fact that they are not restricted by working time rules - allows for longer continuous driving in the case of autonomous vehicles. Companies that will be using autonomous vehicles on long journeys will be able to send these vehicles on long journeys because there will be no working time regulations for drivers, i.e. no need for 45-minute breaks after every 4.5 hours of driving and no need for daily rest. As well as saving time and reducing journey times, this also means that vehicles can be used more efficiently. This partly confirms the working hypothesis that the reasons for introducing autonomous transport will be socio-economic.

Companies in Poland are already considering autonomous vehicles in their development strategies. They will only implement them in their development strategies when there is social proof of the validity of such implementations. One of the experts showed great interest in implementing a solution using autonomous vehicles, as long as it is possible to implement such vehicles without incurring investment costs that exceed their savings, so a vehicle financing system (long-term leasing) would be an important factor.

Determinants for the development of autonomous transport include:

1. the cost of the technology and how it is financed compared to the employee cost including labour law considerations,
2. the range of transportation services (portfolio) provided in relation to potential cost reductions
3. liability for incidents caused by autonomous means
4. security in the event of a cyber-attack, the costs of which will be passed on to those acquiring and using the vehicles
5. infrastructural deficiencies in the form of inadequate preparation of loading and unloading docks,
6. the lack of preparation of sites where the driver ceases to be merely the driver, but also has the task of preparing the vehicle for unloading and ensuring the formalities of the transport documentation - a partial solution to this problem could be the use of transshipment sites, where remotely controlled vehicles would take over the goods previously collected by the driver, but sites where this operation could take place are also lacking.

Transport companies are still wary of innovation in the form of autonomous vehicles. In many European countries, the legislation governing their use on public roads is still in its infancy. This includes Poland, where they come from and where they direct the operations of the companies they manage. The Polish law regulating the circulation of autonomous vehicles on public roads only allows research work related to the testing of autonomous vehicles in traffic on public roads, and even this requires numerous permits issued on the condition that safety requirements are met. Such legal restrictions make it impossible for transport companies in Poland to carry out tests with autonomous vehicles in road conditions.

Experts point to the important factor - a practical game changer - that could be the scenario of using autonomous vehicles in platooning, a solution that could come into general use in the near future. In the first phase, all vehicles moving in a column will be supervised by a driver. This solution will help save fuel and reduce congestion on the roads. As the system develops, drivers will disappear from vehicles moving in a convoy, except for the lead vehicle. Moving a convoy of vehicles supervised by a single driver will be very efficient and can combine the advantages of driver-controlled vehicles with the advantages of system-controlled driving. The driver of the lead vehicle can react to unforeseen situations on the road and take the necessary action if required, while the vehicles moving in formation behind the lead vehicle do not need a driver and will move at an appropriate distance behind the preceding vehicle, reducing fuel consumption and saving money for the company.

The most important task of the systems overseeing the The most important task of the systems monitoring the movement of autonomous vehicles will be safety. For this reason, other drivers may take advantage of this fact and force these vehicles to give way. The system will be forced to yield in order to ensure safety, so there is a need not only to develop vehicle control systems, but also to educate other road users. Experts also highlighted the problems of coexistence between autonomous vehicles and drivers. They noted that the coexistence of the two systems, the traditional one with the driver and the modern one with the system-controlled vehicle, could be a problem due to the unpredictability of the driver's behaviour on the road.

The major courier and postal companies operating in Poland have their own sorting centres between which trucks travel. The Polish Post's current logistics network includes 14 regional sorting centres and 13 local sorting centres, between which more than 5 million parcels are moved every day. The movement of goods between such hubs operating within a single network is easily automated. In addition, such hubs are located outside urban areas on the outskirts of large cities, and the road network between them is highly developed in Poland. According to experts, these are ideal conditions for the development of autonomous truck technology. Just one vehicle per day connected to another in a platoon can save 126,000 zlotys per year just by reducing driver costs. Even with 8 such vehicles, the savings in wages and salaries amount to more than one million zlotys (€ 224,000) per year.

The above-mentioned factors lead the experts interviewed to predict that a breakthrough could occur between 2032 and 2037. During these years, the greatest growth in the use of autonomous vehicles could occur in terms of their implementation in the development strategies of transport companies.

4 CONCLUSION

Transport companies are still wary of innovation in the form of autonomous vehicles. In many European countries, the legislation governing their use on public roads is still in its infancy. This includes Poland, where they come from and where they direct the operations of the companies they manage. The Polish law regulating the circulation of autonomous vehicles on public roads only allows research work related to the testing of autonomous vehicles in traffic on public roads, and even this requires numerous permits issued on the condition that safety requirements are met. Such legal restrictions make it impossible for transport companies in Poland to carry out tests with autonomous vehicles in road conditions. The research carried out confirms the hypothesis adopted about the main economic and social nature of the factors determining the dynamics of autonomous transport development.

5 DISCUSSION

The results of the research show that the prospects for the introduction of autonomous vehicles follow the curve of innovation adoption - the so-called S-curve. Transport market leaders and related companies, such as Uber with autonomous taxis or Lidl and DB Schenker's customer Einride, the manufacturer of autonomous vehicles, are launching pilot programmes in this area. The intensification of these activities has not yet led to a significant exponential increase in the number of companies using autonomous transport. The next stage in the development of autonomous transport is to achieve exponential growth that will eventually outstrip current levels of functionality. Obviously, the realisation of the S-curve development will not lead to the complete elimination of older types of vehicles, but only to their displacement from less useful areas.

Certainly, with the small number of experts (5), the research presented is not fully representative and can therefore be considered as a pilot study. Attempts have been made to reduce this limitation by carefully selecting the experts on the basis of their experience. Nevertheless, a more representative sample should be taken for a similar study in the future.

An important limitation of the presented research, in addition to its qualitative nature, is the period in which the research was conducted, i.e. the first half of 2022. The development of the war in Ukraine and the commercial, economic and social consequences of Russia's aggression against Ukraine may significantly change the perspective on the implementation of autonomous solutions. A protracted war and its further consequences may postpone the projections presented.

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Location of Emergency Treatment Sites After Earthquake Using Hybrid Simulation

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A mass-casualty natural disaster such as an earthquake is a rare, surprising event that is usually characterized by chaos and a lack of information, resulting in an overload of casualties in hospitals. Thus, it is very important to refer minor and moderately-injured casualties, that are the majority of casualties and whose injuries are usually not life threatening, to ad hoc care facilities such as Emergency Treatment Sites (ETSs). These facilities support the efficient use of health resources and reduce the burden on permanent healthcare facilities. In our study, a hybrid simulation model, based on a combination of discrete events and an agent-based simulation, provides a solution to the uncertainty of positioning temporary treatment sites. The simulation methodology used compares between "rigid" and "flexible" operating concepts of ETSs (main vs. main+minor ETSs) and found the "flexible" concept to be more efficient in terms of the average walking distance and number of casualties treated in the disaster area.

Keywords: *Earthquake, Emergency, Temporary Emergency Facility, Hybrid Simulation, Humanitarian Logistics*

DEVELOPMENT POSSIBILITIES OF CONTROLLING SYSTEM IN THE LOGISTICS 4.0 LABORATORY AT THE UNIVERSITY OF MISKOLC

Ákos CSERVENÁK

Abstract: The Logistics 4.0 Laboratory can be found at University of Miskolc in Hungary. This laboratory is well suitable in education and schooling. In education the different material handling equipments can be presented, such as roller conveyor, conveyor belt, loading machine, and AGV with mounted industrial robot as well. The students can find the connection among these elements. These systems can be controlled either manually, or semi-automated, or fully automated. The controller of system is PLC-based. Present system can move different boxes in the system, but without any tracking. In the future, we would like to implement a tracking system, and extracting this also new controlling methods. The paper describes the present system, the already performed modification and the future plans.

Keywords: Logistics 4.0, material handling, tracking system, PLC, automatization

1 INTRODUCTION

Nowadays, the terminology of Logistics 4.0 is increasingly used in industrial life [1]. Research related to the term Logistics 4.0 was also published at the University of Miskolc [2]-[4]. In addition to industrial applications, educational applications have also come to the fore. For this purpose, the High-Tech Logistics Systems Laboratory [5] was established at the University of Miskolc 13 years ago, in yet another building, which was renamed the Logistics 4.0 laboratory due to changes in market demands.

This laboratory is basically part of the educational activity, it is an excellent way to illustrate the individual material handling equipments, their cooperation and automated operation. Previously, the laboratory was in another building, however, after the move, the individual automated units worked separately, as the laboratory's information system was not fully developed. This paper discusses how they work together. The basic goal of the further development is to develop a tracking system, i.e., the path of a product can be followed in the automated process, and the direction of the automated material movement can also be changed depending on the product type.

Chapter 2 of the paper presents laboratories similar to the Logistics 4.0 laboratory located at the University of Miskolc, Chapter 3 details the previous state of the laboratory, while Chapter 4 presents the steps of development so far.

2 SIMILAR LOGISTICS LABORATORIES

This chapter presents two different Logistics 4.0 laboratories located in Europe.

2.1 Logistics 4.0 laboratories in Dortmund, Germany

The Institute for Material Flow and Logistics of the Fraunhofer Institute in Germany has an Industry 4.0 department [6]. The application of Logistics 4.0 was formulated already in 2014 [7]. The Industry 4.0 department is practically a laboratory group with company and research laboratories.

The company laboratories (see Figure 1) enable companies and researchers to actively collaborate at the Fraunhofer Institute for Material Flow and Logistics and implement various innovations in direct collaboration. In the laboratories, it is possible to start from the identification of the topic to the development of a business case ready for the market. In doing so, Fraunhofer IML has created an environment where companies can engage in interdisciplinary collaboration with researchers. In addition to state-of-the-art manufacturing technologies (3D printing, SMD manufacturing, etc.), temporary workplaces are provided for project partners to collaborate on site in lab groups [8].

Figure 1 Industry 4.0 enterprise laboratores at Fraunhofer IML in Dortmund in Germany [8]

In the research halls, logistic research equipment is provided for the researchers. In the localities, it is possible to carry out everything from packaging tests to various identification technologies to swarm intelligence research.

The research facilities can be grouped according to four topic groups [9]:

- Innovationlab Hybrid Services in Logistics: Next-generation industry 4.0 solutions are developed here to increase added value.
- Packaging Laboratory: A laboratory suitable for testing loading units, large cargo drums, transport packaging and pallets.

- Swarm Intelligence: LivingLab Cellular Transport Systems: »Swarm intelligence« for logistics (see Figure 2). The goal is to make supply chains more energy efficient.
- Technology on Demand Lab: Laboratory for the construction of small series and prototypes.

Figure 2 Swarm Intelligence: LivingLab Cellular Transport Systems at Fraunhofer IML in Dortmund in Germany [9]

2.2 Logistics 4.0 laboratory in Norway, Germany

In addition to Germany and Hungary, there is also a Logistics 4.0 laboratory in Norway [10]-[11].

The laboratory was established at the end of 2018 to support the Norwegian university's research activities in several domestic and international projects. The laboratory enables the replication of real logistics processes and material handling activities in production systems, including [10]-[11]:

- several assembly workstations,
- small storage area,
- material handling systems, which includes different types of cars,
- material handling support systems (kanban, visual boards).

The laboratory integrates advanced technologies used in logistics, such as [10]-[11]:

- Advanced simulation software for production and logistics systems,
- Indoor positioning systems,
- Motion recording systems,
- Augmented and immersive reality (AR and IR),
- Visual interactive boards,
- Real-time control.

In 2019, the LOG4.0 lab was expanded with the following [10]-[11]:

- Collaborative robots in manual workplaces.
- Mobile robots in storage.
- Intelligent material handling systems.
- New augmented reality (AR) technologies.
- Aids and tools for intelligent operators and intelligent engineers/managers.
- New technologies for the digitization of production and logistics systems.
- Innovative monitoring technologies for the reliability and maintainability of production systems.

Figure 3 shows details of the AGVs used in the laboratory [12].

Figure 3 AGVS Logistics 4.0 laboratory at NTNU in Norway [12]

3 LOGISTICS 4.0 LABORATORY OF THE UNIVERSITY OF MISKOLC

This chapter details the pre-development state of the Logistics 4.0 laboratory at the University of Miskolc. Figure 4 shows the previous state of the laboratory.

The laboratory consists of the following main parts involved in material handling:

- Automated ULD (Unit Load Device) moving conveyor system
- Shelf system with automated loading machine
- AGV

The automated conveyor system moves the crates, which serve as unit load devices, mainly on a roller conveyor, which is supplemented by a turning table with different types of belt conveyors for each change of direction.

The automated shelving system can take the crates from the ULD moving system and place them in the right place according to a specific schedule.

The AGV can provide automated mobile transport between different points of the laboratory.

Regarding the information system, the individual parts were still operating completely independently of each other, as shown in Figure 5. The solid line represents the path of the possible material flow, while the dashed line represents the individual information flow paths, which can only be seen here within the individual subsections listed above.

Figure 4 Logistics 4.0 laboratory at University of Miskolc in 2021 before development (self-made photo)

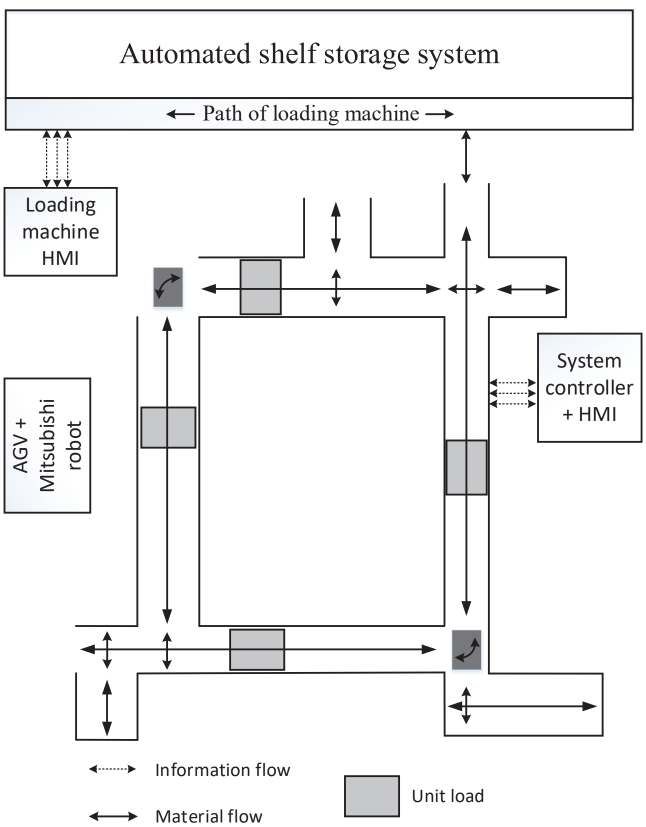

Figure 5 Flows in former state of Logistics 4.0 laboratory at UoM (self-made)

4 CONTROL SYSTEM DEVELOPMENT IN THE LABORATORY

Chapter 4.1 describes the improvements compared to the initial state described in Chapter 3, while Chapter 4.2 summarizes the development so far.

4.1 Steps of laboratory developments

A number of improvements have been made in the laboratory as described below.

Connection of Mitsubishi CCLink communication between the loader PLC and the main system PLC

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In order for the automated material movement between the roller conveyor system and the loading machine to take place, the first step is to establish communication between the two systems. Since the PLCs of the two systems are manufactured by Mitsubishi, Mitsubishi's own CCLink communication protocol was the proper solution. The cabling required for this was established between the two modules of the PLC, as shown in Figure 6.

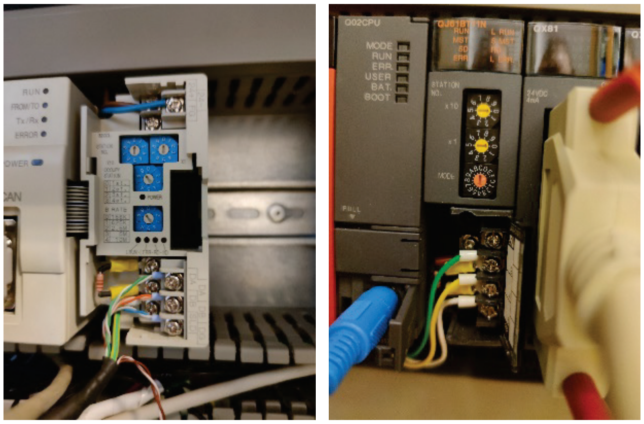

Figure 6 Mitsubishi CC Link communication between the PLC modules of the roller conveyor system and loading machine (self-made photo)

Collection of the PLC variable list of the roller track system

Part of the development is an overview of the existing PLC program and the grouping of the variables ensuring operation as follows:

- Input variables: signals from sensors
- Output variables: signals sent to actuators
- Memory area variables: variables within the PLC
- Timer variables
- Data variables: variables suitable for handling numbers

Placement of two new HMI panels, electronic and communication connections

In the past, a separate palletizing system was part of the laboratory, but due to the discontinuation of the SCARA type robot, it was no longer usable, so it was relocated years ago. The base of the SCARA-type robot (see Figure 4) was still in the relocated laboratory, but due to the lack of function, this part was also removed.
The relocated palletizing system had two HMI panels that could be used again. These HMI panels were dismantled and placed on the right and middle side of the roller conveyor system shown in Figure 4, as illustrated in Figure 7. In addition to connecting the power supply of the HMI panels (230V), it was also necessary to connect the communication channels. One HMI panel is directly connected to the PLC via RS422 protocol, while the other HMI panel uses Ethernet communication, which communicates with the PLC via a router. Furthermore, the establishment of Ethernet communication between the PLC-router made it possible to program the PLC more independently of the location.
The development also included the reprogramming of the graphic display of the HMI panels, with which the system can also be controlled from them.

Figure 7 Placement and connection of two new HMI panels in the laboratory (self-made photo)

Relocation, reprogramming of the former HMI panel serving the roller conveyor system, setting up the shelf system control interface

In addition to the placement of the two new HMI panels, the relocation of the existing HMI panel became essential in the laboratory, as a presenter person had to moved to the other side of the system during a laboratory presentation, which did not look good optically for the audience. Thus, this HMI panel was removed from the side of the control cabinet and transferred to the left side of the system shown in Figure 4. This HMI panel serves as the main HMI panel of the system. The graphic menu of the HMI panel was also supplemented, during which the shelf system could be controlled from this panel as well, not only from the HMI panel next to the loading machine. The control of the shelf system covers the setting of the HOME position and the transfer of boxes between the two systems. Another benefit of the development was that from this time the two systems can cooperate in automatic mode.
The state after relocation can be seen in Figure 8.

Figure 8 HMI panel serving roller track system after relocation (self-made)

Placement and connection of another emergency switch

In order to increase safety, a new emergency switch was placed and connected on the left side shown in Figure 4 next to the central HMI panel (see Figure 9).

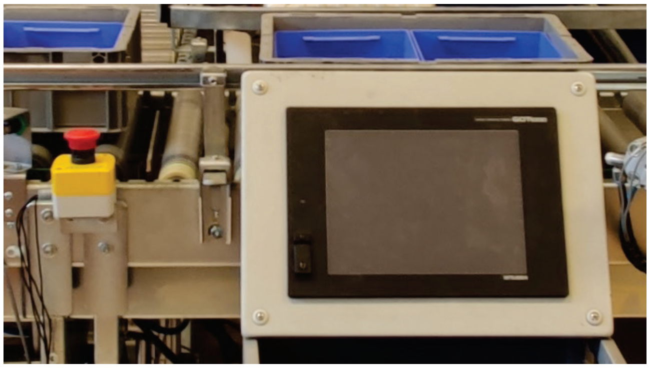

Figure 9 After placing another emergency switch (self-made)

3.2 Current state of the improved laboratory

In addition to the developments, periodic repairs and maintenance were also carried out, for instance, replacement of electric cables or roller conveyor ball belts.

The information system of the system is shown in Figure 10. The system that has been improved so far is illustrated in Figure 11. There is also an information display monitor, which is part of the further development plans compared to this paper.

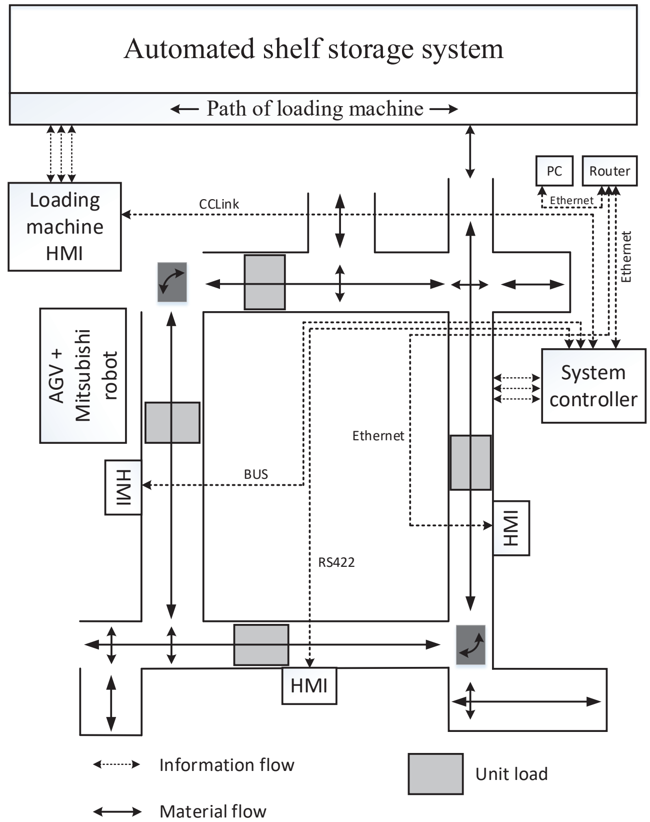

Figure 10 Flows in present state of Logistics 4.0 laboratory at UoM (self-made)

Figure 11 Logistics 4.0 laboratory at University of Miskolc in 2023 after development (self-made photo)

4 CONCLUSION

As a summary, it can be described that the developments so far have significantly contributed to the applicability of the laboratory in the field of education and research. As discussed in the Introduction, the final goal would be to establish a tracking system. Therefore, compared to this paper, the further development steps are as follows: installation of barcode scanners, commissioning of an OPC server for data exchange between scanners and PLC, installation of monitors to display system information, revision of the main program and programming of existing RFID gates.

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Determining Learning Outcomes Relevant for Logistics Higher Education on Sustainability and Industry 4.0

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The ambitious goals of the European Union require companies to transform themselves into sustainable and smart. To do so, for example, in the logistics field, employees who will know how to implement green transport and logistics and how to establish smart systems based on a higher level of digital maturity are needed. This article lists 51 essential topics from Sustainability, Industry 4.0, Logistics 4.0, and Digitalisation areas, further supported by 127 unique learning outcomes gathered through a multi-stage international Delphi study including practitioners and academics. Experts from 6 countries participating in the study first identified the most important topics from the field and the connected learning outcomes in the following rounds, and consequently achieved consensus on the most important learning outcomes that the future workforce in the logistics sector should have. Supporting the logistics sector with a workforce educated based on this framework should help it reach the European Union's strategic goals.

Keywords: *logistics, sustainability, Industry 4.0, digitalisation, learning outcomes, higher education*

CALCULATION OF THE IMPACT OF THE WAREHOUSE MANAGEMENT SYSTEM ON THE GREEN DIMENSION OF WAREHOUSE OPERATIONS

Simona ŠINKO, Brigita GAJŠEK

Abstract: The intensive digitalization of business systems gives impetus to the development of a wide variety of software tools, which are intended to reduce the time spent on work and relieve workers of the burden of weighing between different task implementation options. Introduction of software support affect the greenness of business activities. This paper presents current stage of research on the influence of the implementation of the warehouse management system on the green dimension of work in the warehouse and proposes a generally applicable calculation to determine the change in CO_{2e} emissions due to the warehouse management system implementation.

Keywords: Warehouse Management System, green, intra-logistics, CO_{2e} emissions, energy consumption.

1 INTRODUCTION

To keep global warming below 2°C, greenhouse gas (GHG) emissions must be reduced by around 13.5 Gt CO_{2e} by 2030 [1]. This call also addresses transport and logistics activities which contributed approximately 7.5 Gt CO_2 in 2015 or 18% of global emissions by human activity [2]. 13% of this is estimated to be allocated to "logistics buildings" [3]. According to Cliff with co-authors [4] and McKinnon [3], the transport and logistics sector will be the most difficult to decarbonize. McKinnon [3] observed, "Very little data is available on GHG emissions from the buildings and terminals in which goods are stored, handled and transhipped." According to his estimates, warehouses generate about 20% of the transport emissions in the USA [5], and about 11% in the U.K. [6].

Besides the guidelines of the United Nations Environment Program, companies are encouraged to take action by a growing interest among consumers to patronage environment-friendly products [7]. Additionally, all will be affected by the Corporate Sustainability Reporting Directive (CSRD), which underpins the EU Green Deal and updates and replaces the Non-Financial Reporting Directive (NFRD). In 2024, large companies of public interest with more than 500 employees will be obliged to report on Sustainability. Logistics companies will not be an exception.

Since measurement and improvement of the environmental performance of companies have become more relevant, standards, guidelines, and tools have been developed [8]. Many derive from Life Cycle Assessment (LCA), which is aligned to ISO 14040 & 14044. Both ISO standards are used to systematically assess the environmental impacts of the entire life cycle of products and services systems. Due to LCA complexity, it is not often used to assess logistics services. A system specifically for the logistics sector and its services was not available until 2012. Aditionally, in the field of logistics, research activities till 2016 focused on decarbonizing supply chains through increasing efficiency without considering logistics centers as important nodes of the network, as explained by Dhooma and Baker [9], Marchet and co-authors [10], and Fichtinger and co-authors [11]. With the aim of launching a comprehensive approach and unifying the efforts of various stakeholders, the industry initiated the Global Logistics Emission Council (GLEC) to develop a globally harmonized framework for logistics emissions accounting covering all modes, transfers and regions [8]. Accredited by the Greenhouse Gas Protocol, the GLEC Framework is the recommended method for reporting emissions to CDP, setting Science-Based Targets, and aligning with a growing number of other methodologies and industry standards [12]. CDP [13] runs the global environmental disclosure system. Each year CDP supports thousands of companies, cities, states and regions to measure and manage their risks and opportunities on climate change, water security and deforestation.

Several industry organizations, shippers, logistics providers, and their representatives work on further developing guidelines and principles for emissions calculations for the transport modes they are working with. Therefore, guidelines and frameworks for air, road, sea, inland waterways, and rail are still in progress in 2023. Logistics hubs are a weak link as far as a harmonization of the various levels of carbon footprinting maturity of the individual transport modes is concerned, despite their importance within the transport chain [14].

Warehouses are a kind of hub and are important nodes in each supply chain and every industry. For decades, the most important driver for expanding warehouse space was the e-commerce sector and the growing demand for mass customization [15]. During the pandemic, a shift towards online shopping continued today's growth trend. For example, commercial real estate services company CBRE [16] surveyed 100 major industrial occupiers throughout the U.S. on their upcoming plans. The majority of them distribute and manufacture within the supply chain. 64% plan to expand their U.S. logistics footprint in the next 3 years, 47% for more than 10%. 44% plan to achieve expansion goals by partnering with a developer to lease build-to-suit facilities, and 37% plan to land and self-develop their facilities. Their planned ways to meet net zero carbon targets are switching to LED lighting, using alternative energies on-site, using electric material handling equipment, charging for an electric delivery fleet, and capturing rainwater. All ways of reducing the footprint refer to building skin and building technology, but none to intra-logistics.

Warehouses contribute to the generation of greenhouse gases (GHG) and their impact on global warming can no longer be disputed [14]. The building sector is responsible for 36% of CO_2 emissions and around 40% of energy consumption in the European Union [17]. Therefore, the EU's new buildings, including warehouses, will have to be nearly zero-energy buildings.

In the case of warehouses, synergy effects in building, installed technology, and intra-logistics should be considered suitable levers to lower energy demand and related CO_2 emissions [18]. Freis, with co-authors [18], developed with a systemic approach an integrated analytical model for energy calculation and reference-building models for different types of logistics centers. They examined the interrelations and impacts of design options for intra-logistics, building technology, and building skin on energy demand. The results showed that it is possible to lower CO_2 emissions significantly. However, there are apparent differences between the different types of logistics centers and the impacts of different design options. A manual and a fully automated warehouse comparison shows a significant difference in energy used for material flow, handling, and storage equipment, where manual storage is the most rational. In such a warehouse, further reduction of energy consumption is possible by heating and cooling applications with renewable energy sources in connection with good insulation. In the case of a fully automated warehouse, the share of energy demand of the intra-logistics equipment predominates from those from building technology and building skin. Freis, with co-authors [18] do not mention the impact of the software on energy consumption or CO_2 emissions.

The central software in warehouses is a Warehouse Management System (WMS). When sellers and users of WMS describe the effects of its use, they state many things, but there is still no assessment of the impact on energy consumption and CO_2 emissions. We assume from previous research that the owners of manual warehouses will gain much more in terms of energy and CO_2 emissions reduction if they invest in the energy reconstruction of the warehouse than in the implementation of a WMS. However, WMS could make a significant contribution to a semi-automated warehouse and an automated warehouse.

WMS is a part of Information Communication Technology (ICT). In 2014, Hankel and co-authors [19] proposed A maturity model for Green ICT to give organizations insights into and understand the total environmental impact of Green ICT. The model includes three domains: Green ICT in the organization, Greening of ICT and Greening of operations with ICT. The operational use of the WMS coincides with the domain Greening of operations with ICT and its attributes: (1) travel reductions with ICT, (2) space reductions with ICT, (3) energy Reductions with ICT, (4) paper reductions with ICT, (5) other reductions with ICT, (5) environmental awareness and decision support. Listed attributes could be used for calculating impact of WMS implementation.

In the scientific literature, the effects of the use of WMS are well studied, except for the effects in the light of sustainability. Sustainability assessment of WMS is a highly significant task and it is urgently needed [20]. Given that the EU is introducing mandatory reporting for companies on sustainability at the company level from 2024 and that the scientific literature does not offer quantified values due to the use of WMS, this paper attemps to connect both efforts through a proposal for calculating the impact of WMS on the green dimension of warehouse operations. In doing so, he scientific literature is also considered in the field of greening operations with ICT. WMS vendors will need to present greening of ICT [19] in the form of software (SW) development, network infrastructure, end-user ICT equipment etc. In addition, they will be expected to disclose to the potential customer the impact of using a WMS on their green business component or at least advise the customer on how to calculate it.

Based on the preliminary research, the paper answers two research questions:

RQ1: What is the current state of research on calculating the impact of WMS implementation on the green component of sustainability?

RQ2: How could the impact of WMS implementation on CO_{2e} emissions be calculated without requiring the collection of specific data just for this purpose?

In section 2, we define warehouse as a system and WMS. Additionally, the research findings on the effects of WMS use on business performance are briefly summarized. The methods are described in section 3, and the results in section 4. The paper ends with a conclusion.

2 THEORETICAL BACKGROUND

2.1 Warehouse as a system

A warehouse is a type of logistics center, so we will summarize its characteristics and building blocks as a starting point. The system logistics center is regarded as a technical object system according to Ropohl [21]. Freis and co-authors [18] continue that it comprises the areas of intra-logistics, building technology, and skin, according to the implementations and alternatives of which the individual logistics centers differ significantly from each other. The location of the site and the building skin are set as the boundaries for the system logistics center. The environment on the site of the logistics center is set as the hierarchical super-system. The area's building technology, building skin, and intra-logistics are treated as sub-systems. Energy, elements in material flow, and information are determined as inputs. Energy is converted into the output through mechanical work, light, or heat with specific losses. This energy use of the system elements serves to generate logistics performance.

As Freis and co-authors [18] visualised in Fig.1, in intra-logistics processes, system elements are differentiated into process-oriented and process-independent elements.

Elements of the sub-system intra-logistics are process-oriented due to the dependence of their energy use on received orders from customers. Process-independent elements include the sub-systems building technology and building skin. The energy use of these elements is not linked to the number of received orders. The system logistics center interacts with the environment via the building skin. This idealized consideration decreases the complexity of the system and enables the development of manageable models. Otherwise, too many variables need to be considered in the model.

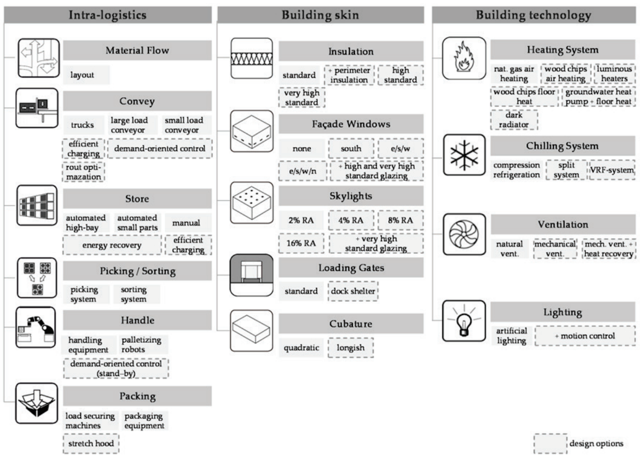

Figure 1 Logistics centers' identified and classified system relevant base elements [18]

2.2 WMS

A warehouse serves as a commercial facility for storing and buffering goods and is utilized by manufacturers, importers, exporters, retailers, and transport companies. Logistics personnel use a computer application known as a WMS to improve the efficiency of warehouse operations and maintain accurate inventory records. This database-driven software directs the flow of goods and records transactions within the warehouse. A typical WMS comprises features for managing the receiving, storage, order picking, packing, and shipping processes [22, 23]. WMS has been recognized as an element of a green warehouse more than a decade ago. Improving the efficiency of transportation equipment can significantly reduce energy consumption and CO_2 emissions. By implementing a paperless WMS, warehouses can further increase their efficiency and reduce paper consumption, improving their environmental image [24].

A WMS collects, stores, and delivers data on products, resources, and processes by recording transactions and transferring them to other modules of the company's enterprise resource planning (ERP) system [25]. More precisely, the purpose of a WMS may include (1) achieving transportation and production cost savings, (2) taking advantage of quality purchase discounts and forward buys, (3) aligning with the firm's customer service policies, (4) adapting to changing market conditions and uncertainties, (5) overcoming geographical barriers between producers and customers, (6) minimizing logistics costs while maintaining the desired level of customer service, (7) supporting the just-in-time programs of suppliers and customers, (8) offering customers a variety of products in a single order, (9) providing temporary storage for materials to be disposed of or recycled, and (10) acting as a buffer location for transshipment [23].

The types of WMS can be classified as Basic, Advanced or Complex [26]. A basic WMS is designed to assist with stock and location control, primarily through information registration. It can generate storage and picking instructions, which may be displayed on RF terminals. The warehouse management information provided is basic, mainly focused on throughput. An advanced WMS goes beyond the functionality of a basic WMS by enabling the planning of resources and activities to synchronize the flow of goods in the warehouse. It primarily focuses on throughput, as well as stock and capacity analysis [27]. A Complex WMS offers additional features such as data-driven planning, traceability, dock allocation, and automated process supervision and control using automated guided vehicles or automated storage and retrieval systems [28]. The role of a WMS in enhancing warehouse performance is acknowledged by both practitioners and researchers [29].

SW providers market WMS solutions by highlighting the software's functionalities. The websites of the three WMS providers were carefully reviewed to determine highlighted functionalities. The advertised functionalities are presented in Table 1.

Table 1 Advertised WMS's funcionaties

WMS functionality	Different WMS solutions		
	WMS(1)	WMS(2)	WMS(3)
Tracking stocks by different parameters	✓	✓	✓
Cross docking system	✓		✓
Integration with any ERP system	✓	✓	
Use of different order-picking policies	✓		✓
Route optimisation	✓	✓	✓
Analysis of warehouse capacity utilisation		✓	
Sorting orders according to stock and priority		✓	✓
Printing of labels / documents		✓	

WMS providers focus mainly on functionalities that influence process time, such as tracking transport and storage units (TSU) by different parameters, executing different order-picking policies, route optimization, etc. When advertising the cross-docking system, they highlight that WMS can reduce space requirements and speed up shipments to customers. For route optimization functionality, it is exposed that using WMS saves time and significantly reduces the length of the routes. It also emphasizes single data entry, paperless transactions, and fast and accurate data capture to reduce errors in the data processing itself. The benefits advertised by WMS providers do not include the impact of SW on the greening of warehousing processes. According to advertising, WMSs do not monitor the CO_{2e} emissions produced with warehouse activities per a specific

TSU. This functionality may be necessary to provide data for product emission records in the future.

In the past, authors have mainly focused on the impact of WMS use on time spent in warehouses on processes. Ramaa et al. [27] performed a case study at three warehouses of Indias' biggest retail company. A study was conducted to analyze the impact of implementing a WMS in these warehouses to enhance efficiency. In these warehouses, goods were received large quantities and stored in racks. When orders were received, the items were picked, packed, and shipped, a cumbersome process due to the lack of a WMS. There was no system in place to schedule the arrival time of vehicles. Using a value stream map, where WMS was added to the process, they reduced process time by an average of 69.09%. The highest time improvement has been shown for dispatching (94.2%) and the lowest for put-away (36.84). The required workforce was reduced by 40%. Authors described the benefits of implementing WMS in time scheduling of vehicles, enabling advanced shipment notes for prior information about received goods, WMS-assisted put-away of goods, 100% goods traceability, algorithm-based picking, auto-updating of information, reports for decision-making, and reduced paper consumption from 19 to 4 sheets per order. Baruffaldi and co-authors [30] prepared the simulation in which they compared the performances of the picking activities (traveling time) based on different WMS features. They proved that different scenarios (FEFO, FIFO) have different performances in terms of travel reduction. These researches show that the use of WMS has a significant impact on performance in the warehouse.

The link between energy consumption and WMS use has also been researched. Boenzi and co-authors [31] stated that selecting forklifts equipped with different engines could optimize the energy required by order picking. However, changing forklift trucks for electric alone can result in less green solution as when combined with storage configuration and optimization of intra-logistics activities. Considering energy consumption, it is important to determine the most appropriate disposal site and route. A WMS can significantly help to achieve the above. Ene and co-authors [32] also demonstrate how green principles can be applied in warehouse operations. They proposed a genetic algorithm (GA) approach to determine efficient order-picking warehouse routes to minimize energy consumption. The results using GA were not compared with the results without using GA.

Reviewed papers focus on energy savings during order-picking. The latest literature review on research about energy consumption in warehouses is done by Ene and co-authors [32]. To the best of the authors knowledge, there is no research about the expected impact of WMS implementation on the quantity of CO_{2e} emissions.

2 METHODS AND METHODOLOGY

In the research work, we combined inductive and deductive methods. The inductive method is understood as the systematic and consistent use of an inductive way of reasoning in which, based on individual and specific facts, a conclusion is reached about a general judgment. Researchers progress from observations of specific individual cases and factors to general conclusions, from known individual cases to the unknown, general, from the studied to the unstudied, and from a larger number of individual phenomena, a generalization is made [33]. The deductive method is the systematic and consistent use of a deductive way of concluding. Special, individual conclusions are made from general points of view, from general points to specific individual conclusions, and from one or more statements a new statement is made, which is derived from previous statements [33].

The inductive-deductive method was used to explain the findings, discover new insights and new inteconections, and predict future events. We implemented it in the following stages:

- gathering facts by observing real work in the warehouse;
- creation of theses;
- conclusion based on literature review and observations.

In November 2022, we observed work in a non-automated warehouse, where logistics units are moved with electric forklifts. The warehouse was in transition due to the introduction of a WMS. We were interested in the impact of the introduction of WMS on the physical appearance of works and on the type of data captured before and after the introduction of WMS.

We compiled a list of staff operations before and after the introduction of the WMS and drew conclusions about the impact on the consumption of energy, materials, human resources, and the amount of waste.

The next step was to create a general formula that would help estimate the impact of WMS on the green component of the warehouse for any warehouse. We filled the missing insight into the European Commission's approaches to the realization of environmental goals with a review of the literature. In this way, we concretized very generalized guidelines on the example of a warehouse. Furthermore, we assumed that scientists, with the help of simulation models of specific processes in warehouses, report on the concrete impacts of process activities on the consumption of energy products. We found that the results are present, but there are still too few of them to be able to immediately generalize on the basis of the impact of the WMS implementation on the greenness of the warehouse. Much of the thinking and reasoning has been written down in the introductory part of this paper. We justified the need to track changes in the amount of CO_{2e} emissions before and after the use of WMS. For this purpose, based on the implementation of the inductive-deductive method in the results, we propose a methodology to calculate change in the quantity of CO_{2e} emissions due to WMS implementation.

3 RESULTS

The proposed methodology for calculating the change in produced CO_{2e} emissions due to the introduction of WMS consists of six steps, shown in Fig. 2.

The proposed steps are deduced from the Global Logistics Emissions Council Framework [12], literature review and gathered facts by observing real work in the warehouse. The fact is, that all companies will have to start reporting on CO_{2e} emissions in a standardized way in the following years. For this reason, we proceeded from the already standardized procedure and adapted it to the extent that it can be used to calculate the changes resulting from the introduction of the WMS.

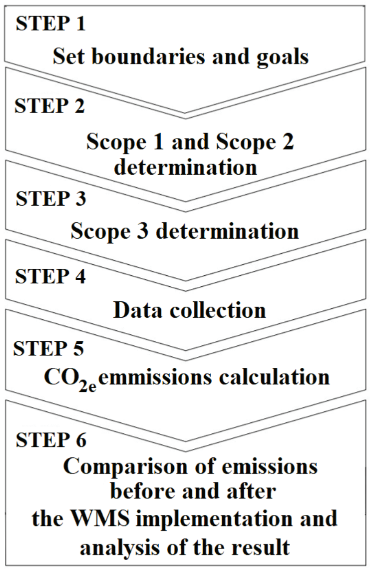

Figure 2 Methodology for CO_{2e} calculation

STEP 1: Set boundaries and goals

Two activities must be carried out as a part of the first step to prepare a reliable and transparent calculation output. The first activity is to define the goal of the calculation. The fundamental goal should be: "Calculating the difference in emissions before and after the implementation of WMS."

However, the calculation can also be used for internal analysis to support decision-making and carbon footprint reporting.

The second activity is to set analyzed system boundaries. Setting boundaries is a critical activity since the success of the calculation depends on what we include in the calculation. Proceeding from Fig. 1 [18], the boundary is set on intralogistics, excluding building skin and building technology from consideration because WMS implementation does not influence them. With the help of Fig. 1, the elements of each specific warehouse under consideration must be listed and described in detail.

This step cannot be generalized because intralogistics systems vary significantly in configuration from warehouse to warehouse. Fig. 3 shows intralogistics elements, inputs to the warehouse system and outputs from it in the observed warehouse, which WMS directly or indirectly manages. These are the sources of CO_{2e} emissions. Emission sources are divided between three standardized scopes. The figure serves as an aid to determine which elements are relevant in the calculation. The one that reflects the use of WMS is relevant.

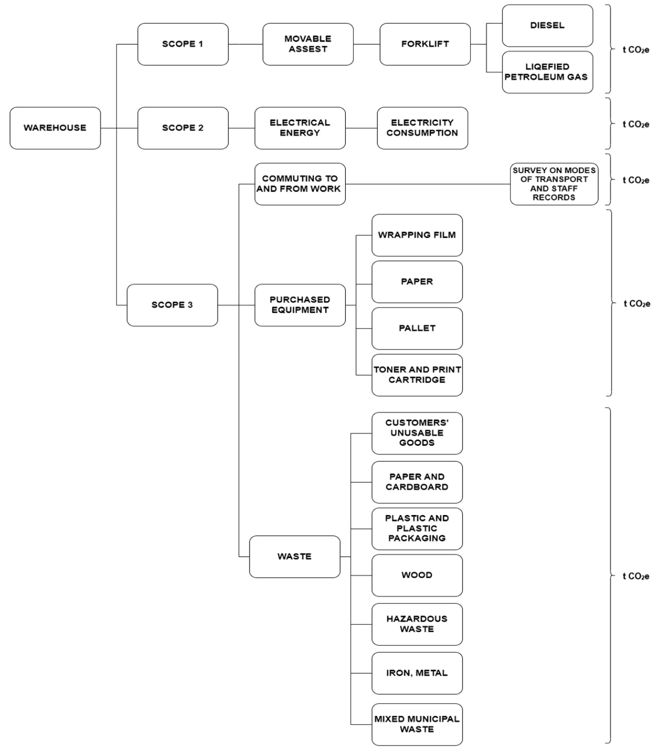

Figure 3 Mapping the links between sources and emissions

STEP 2: Determination of Scope 1 and Scope 2

Scope 1 emissions are those that a company causes by operating the things that it owns or controls. In the warehouse, these can be a result of running machinery to offer services, driving vehicles, heating the building and powering computers. As can be seen, all the listed activities are not related to the use of WMS, for example, heating or cooling.

In order to perform the calculation, it is necessary to obtain data on the consumed quantities of fossil fuels for the operation of mobile assets because of carrying out tasks in the warehouse. After gathering the quantities, it is needed to obtain data on emission factors for each type of source. Emission factors are usually obtained from publicly available records or directly from suppliers. It is important to note that different fuels have different emission factors, and therefore, it is crucial to convert fuel quantities separated by fuel type to CO_2e.

Scope 2 emissions are created by the production of the energy that an organization buys. Warehouses use electricity for running computers, operating warehouse equipment, powering various systems, such as process motors, fans, pumps, compressed air systems, facility lighting etc. When data on the impact of WMS on CO_2e emissions are being obtained, lighting infrastructure must not be changed, or, for example, a new cold storage facility must not be started. The only new thing are the changes related to the WMS implementation.

STEP 3: Determination of Scope 3

The company itself does not produce Scope 3 emissions. They differ from Scope 2 as they cover emissions produced by customers using the company's products/services or those produced by suppliers making products that the company uses. When determining Scope 3, it is necessary to look at the list of everything that can fall into this scope and to think critically about what comes into play for tracking the impact of the WMS implementation. For the observed warehouse, we placed in Scope 3 employees commuting to and from work, purchased material for equipment, and produced waste.

STEP 4: Data collection

After determining the scope and mapping the links between sources of emissions, it is time to collect the data. When collecting data, we need to ensure that the data is accurate and that the emission factors are adequately determined.

For obtaining data on quantities of used fossil fuels under Scope 1, data can be collected from various sources such as fuel and refrigerant invoices, fuel management systems, and annual expenditure records. The fuel consumption is taken into account for the entire round trip. It should cover fuel usage associated with full, partially-loaded, and empty trips.

For accurate data on electricity consumption (Scope 2), the most reliable source is the invoice from the electricity provider. Electricity consumption is usually measured in kilowatt-hours (kWh) and should be reported for a warehouse facility measuring point. It is crucial to record the location (country, state, or city) from where the electricity is purchased, as the emissions are linked to the energy source of the specific electric grid.

The data about the quantities of different purchased materials for equipment (Scope 3) can be obtained from the procurement system. The data on the quantity of each type of waste (Scope 3) can be obtained from waste collection invoices, but more precise data can be obtained by weighing.

Three methods are available for calculating emissions caused by employee commuting. Fuel-based method requires multiplication of the quantity of fuel consumed during commuting with relevant emission factor for that fuel. Distance-based method require collecting data on commuting patterns from employees, such as the traffic mode and distance traveled, and multiplying quantities with relevant emission factors for the traffic modes used. The last one is an Average-data method, which calculates emissions from employee commuting by using average data, such as national statistics, on commuting patterns [34].

As the goal is to compare emissions before and after the introduction of WMS, it is crucial to collect data before the implementation of WMS and after the full implementation of WMS. We always collect data for a period. The minimum period is one month, following the frequency of receiving invoices for energy products. The data collected must be verified, and the quality of the data must be assessed.

STEP 5: Calculation of emissions

The first activity in this step is to collect the emission factors needed for the calculation. The emission factors for the different substances and materials can be found in the source [12]. Emission factors must be obtained carefully, as choosing the wrong factor can lead to noticeable errors.

The second activity is calculating all emissions mapped on Fig. 3. The calculation for fuel emissions is based on Eq. (1) [12]:

$$\text{kg } CO_{2e}(\text{fuel}) = \sum_{i=1}^{n}\left(\text{fuel (kg)} \times \text{fuel emission factor } \left(\frac{\text{kg } CO_{2e}}{\text{kg fuel}}\right)\right) \quad (1)$$

where i presents the type of fuel used for movable assets.

The calculation equation for electricity emissions is Eq. (2) [12]:

$$\text{kg} CO_{2e}(\text{electricity}) = \sum_{i=1}^{n}\left(\text{electricity (kWh)} \times \text{electricity emission factor } \left(\frac{\text{kg } CO_{2e}}{\text{kWh electricity}}\right)\right) \quad (2)$$

where i presents the type of used electricity.

Emissions caused by employees' commuting are calculated similarly to emissions from using fossil fuels in Scope 1 when data on spent fuel quantities are available for employees commuting (Fuel-based method). The calculation is presented in Eq. (3a).

$$\text{kg } CO_{2e}(\text{commuting}) = \sum_{i=1}^{n}\left(\text{fuel (kg)} \times \text{fuel emission factor } \left(\frac{\text{kg } CO_{2e}}{\text{kg fuel}}\right)\right) \quad (3a)$$

where i presents the individual employee.

Emissions caused by employees' commuting based on the Distance-based method are calculated using Eq. (3b) [34].

$$\text{Total distance traveled by vehicle type} = \sum_{i=1}^{n} \text{daily one} - \text{way distance between home and work (km)} \times 2 \times \text{number of comuting days per year}$$

$$\text{kg } CO_{2e}(\text{cummuting}) = \sum_{i=1}^{n} \text{total distance for each vehicle type (km)} \times \text{emission factor}_i \left(\frac{\text{kg } CO_{2e}}{\text{km}}\right) \quad (3b)$$

where i presents the type of fuel used for commuting.

Emissions caused by employees' commuting based on the Average-data method are calculated using Eq. (3c) [34].

$$\text{kg } CO_{2e}(\text{commuting}) = \sum_{i=1}^{n} \text{total number of employees} \times \text{\% of employees using mode} \times \text{one way commuting distance (km)} \times 2 \times \text{working days per year} \times \text{emission factor}_i \left(\frac{\text{kg } CO_{2e}}{\text{km}}\right) \quad (3c)$$

where i presents the type of transport mode used.

The GHG emissions for each type of material for equipment and type of waste are calculated with Eq. (4) [12].

$$\text{kg} CO_{2e}(\text{equipment and waste}) = \sum_{i=1}^{n} \text{quantity}_i \text{ used} \times \text{emission factor}_i \left(\frac{\text{kg } CO_{2e}}{\text{kg fuel}}\right) \quad (4)$$

where i presents the individual type of purchased material for equipment and individual type of waste.

Once all 4 emission factors Eq. (1), (2), (3), and (4) have been calculated, they only need to be summed together to obtain the total GHG Emissions with Eq. (5a) and (5b). Total emissions must be calculated separately for the period before and the period after the implementation of WMS.

$$\text{Total GHG Emissions}_{\text{before WMS}} = \text{kg CO}_{2e}(\text{fuel})_{before} + \text{kg CO}_{2e}(\text{electricity})_{before} + \text{kg CO}_{2e}(\text{commuting})_{before} + \text{kgCO}_{2e}(\text{equipment and waste})_{before} \quad (5a)$$

$$\text{Total GHG Emissions}_{\text{after WMS}} = \text{kg CO}_{2e}(\text{fuel})_{after} + \text{kg CO}_{2e}(\text{electricity})_{after} + \text{kg CO}_{2e}(\text{commuting})_{after} + \text{kgCO}_{2e}(\text{equipment and waste})_{after} \quad (5b)$$

The additional but important activity in Step 5 is verifying and validating the calculation. However, it is essential to note the data sources and all the assumptions on which the calculation was based.

STEP 6: Comparison of emissions before and after the introduction of WMS and detailed analysis

The final step is to calculate the change in GHG Emissions produced. Improvements are calculated as the difference between the total emissions before and after the introduction of WMS. The calculation is shown in Eq. (6).

$$\text{Difference in GHG Emissions} = \text{Total GHG Emissions}_{\text{before}} - \text{Total GHG Emissions}_{\text{after}} \quad (6)$$

The result only gives the change in total emissions. In the case of a positive result, it is proven that the implementation of the WMS system has an impact on the reduction of emissions. However, in order to determine which element has the most impact on the reduction and where there are still reserves, it is better to look directly at the quantity of materials and fuel consumed. In more detail, this means calculating the difference between fuel consumed (Scope 1), electricity purchased (Scope 2), purchased materials for equipment and produced waste (Scope 3) before and after the implementation of the WMS system - using formula Eq (7).

$$\text{Difference in quantity of used material/fuel[kg]/[kWh]} = \text{Quantity}_{\text{before}} - \text{Quantity}_{\text{after}} \quad (7)$$

This more detailed analysis is essential because a significant difference may have been made regarding one item but not strongly reflected in the overall calculation due to a low emission factor. On the other hand, there may be a significant change in the overall calculation, but this is due to a slight change regarding the item with a higher emission factor.

4 CONCLUSIONS

The European Union has set ambitious goals to transform itself into a carbon-neutral society as soon as possible. In this way, society becomes committed to reducing the emissions of its activities. If this mentality is transferred to the level of software solutions, developers and providers of information solutions must minimize the CO_{2e} emissions of the development of information solutions and the installation of the system necessary for the functioning of the information solution. The user of information solutions will also be interested in the impact of the introduced information solution on the CO_{2e} emissions of the activities that the information solution supports. At the moment, we cannot calculate specific shares. Calculating the impact of introducing different WMS on CO_{2e} emissions for different warehouse systems is a challenge for future research. From literature review, it is only proven that WMS implementation can contribute to reducing CO_{2e} emissions to such an extent that introducing electric forklifts becomes a green solution, which is not always true otherwise.

The exact quantity of CO_{2e} emissions before and after the introduction of WMS could be also determined by computer simulation. However, the computer simulation of work in a manual warehouse before implementation of WMS, or a warehouse where humans carry out the work according to their decisions and judgements, is an almost impossible challenge because companies do not have collected data. Data in electronic databases starts to be collected only after the introduction of WMS. In this way, we justify the reasonableness of the calculation developed in the paper, which is based on the comparison of input and output quantities in warehouse processes, about which the companies have data before and after the introduction of WMS.

The proposed approach has potential limitations, such as the impact of external factors and changes in emission factor data. For instance, during the time in which a WMS is implemented, changes in transportation infrastructure could also impact the CO_{2e} emissions. Special attention during the calculation should be given to considering other changes in the warehouse system at the time of data collection for the calculation, which could distort the result.

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DEVELOPMENT OF A SIMULATION ENVIRONMENT FOR MOBILE ROBOTICS APPLICATION IN MANUFACTURING INDUSTRY

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Abstract: Mobile robotics has a positive impact on the manufacturing industry's efficiency and productivity, and the emergence of Industry 4.0 technologies, such as the Internet of Things and 5G, has further amplified this impact. Although the use of mobile robots is increasing, the rapid technology development has caused a skill gap that slows down the implementation of the latest solutions in the manufacturing companies. To bridge this gap, a simulation environment for mobile robotics in manufacturing industry has been developed and the development process based on a review of current trends in mobile robotics and intralogistics is described in this paper. Used development process resulted with an environment that utilizes cutting-edge technologies to simulate the most common use cases of mobile robotics in the manufacturing industry. Developed simulation environment facilitates research, and work-based training and education, and has the potential to positively impact the implementation of these systems in manufacturing companies.

Keywords: automated guided vehicles, autonomous mobile robots, industry 4.0, intralogistics, smart factory

1 INTRODUCTION

Industry 4.0 marks a new era in industrial practices, embracing innovative technologies like autonomous vehicles and the Internet of Things (IoT). This marks the first time in history where such a dramatic shift is happening at an unprecedented pace, leading to the Fourth Industrial Revolution. The IoT can turn a physical space, such as a factory or warehouse, into a cyber-physical system that brings together technology, people, and processes. Thanks to the decreasing costs of autonomous vehicles and their ability to connect with the IoT, many manufacturing and logistics companies (79.9% and 85.5%, respectively) are considering digital transformation as a positive step forward compared to using traditional industrial trucks and lifts [1]. To achieve this digital transformation, it would take replacing industrial trucks and lifts with mobile robots. Mobile robots are devices that move independently to achieve a set of objectives. They are used in various fields, including factories, healthcare, security, search and rescue, and homes. Automated guided vehicles (AGVs), invented in the middle of the 20th century, are the most common type of mobile robot used in industrial applications to move materials within a facility with autonomous mobile robots (AMRs) close behind. As robot capabilities and sensors improve and safety standards are developed, mobile robots are increasingly used in manufacturing and other industries to meet the growing demand for automation [2]. Various types of prototype mobile robots have been developed for manufacturing applications, such as material tracking vehicles, mobile manipulators, and aerial drones.

Autonomous Mobile Robots (AMRs) and Automated Guided Vehicles (AGVs) are both used in industrial environments for material handling. However, AMRs are more flexible than AGVs as they are autonomous and can make decentralized decisions such as dynamic routing and scheduling. AMRs are also smaller and more agile than AGVs, allowing them to access more areas and be integrated to a higher degree in workstations, enabling manufacturing flexibility. Traditional conveyor connections between workstations can be replaced with AMR systems, supported by Artificial Intelligence to navigate through dynamic environments and provide optimized routing. This has led to the introduction of smart intralogistics systems that use AMRs [3], [4]. Generally, AMRs can be split into three broad groups [5]:

- AMRs that move inventory within a facility
- AMRs that assist in the picking process
- AMRs that are a flexible sorting solution.

According to a recent McKinsey study, there is a growing demand for smaller and cheaper robots. The cost of producing robots has decreased due to increased production in lower-cost regions, resulting in a more than 50% drop in average robotics costs since 1990. Robotics engineers, who were once rare and expensive specialists, are now more widely available. Advancements in computing power, software development techniques, and networking technologies have made it easier and less expensive to assemble, install, and maintain robotic production systems. These trends are expected to continue and have a positive impact on the growth of the robotics sector [6].

One of these advancements is the forementioned Internet of Things. The IoT is the connection of smart objects through embedded systems, creating a network of devices that communicate with each other and humans and has the potential to transform manufacturing through automation, digitization, and connectivity. This connectivity enables manufacturers to remotely monitor and control business operations, providing benefits such as real-time performance visibility, predictive maintenance to minimize downtime, and remote diagnostics and support. Indoor positioning systems, a key IoT application, could profoundly impact manufacturing operations by attaching inexpensive sensors to objects like AGVs or AMRs. This transformation could turn a factory into a cyber-physical system, allowing for advanced data analytics to optimize productivity. Beyond technical and operational factors, social factors like people and business culture are also critical success factors within a lean manufacturing, but also a smart manufacturing context [1].

The need for formalized training in smart manufacturing (SM) has gained global attention, leading to the reformation of practical education systems. The goal is to provide STEM education through interdisciplinary approaches that connect academic concepts with real-world operations. For example, an Android-based application course has been developed using open-source computer vision algorithms, and a multidisciplinary platform has been presented for an undergraduate laboratory program that covers embedded systems and robotics [7]. Virtual technology and remote laboratories have been used as pedagogical tools to enhance the learning experience, and hands-on training has been explored through innovative equipment or platforms with authentic content [7]. However, most education platforms only focus on specific stages of the SM process, leading to a lack of comprehensive knowledge and skills [7],[8]. To address this, various education systems have been proposed, such as the integration of sensors and actuators to achieve intelligent cooperation, monitoring, and control [7]. Mobile robots have had a significant impact on the manufacturing environment in recent years, particularly in smart manufacturing factories [7]. They can be used in tandem with automation equipment or machines for various tasks, including warehousing, logistics, processing, and testing, which allows for a fully automated factory. Additionally, mobile robots have become a key piece of equipment for interdisciplinary education, allowing students to integrate different fields of study into their learning [7].

This is a very positive thing because the rapid pace of technological advancement in Industry 4.0 has led to a considerable disparity between the skills possessed by employees and the constantly changing demands of their job roles. This has created a need for fresh and more efficient methods of talent development. Middle managers are now being acknowledged as a vital yet neglected component of talent development because of their pivotal function in managing organizational changes [8]. In addition, conventional hiring practices such as lateral hiring (which is the process of hiring employees who are already working in a similar position at another company) are not effective in the context of Industry 4.0, as they involve a futile search for non-existent talent [8].

Even before the global pandemic, workplace automation led to the evolution of job roles and the need for employees to acquire imperative skills to keep up with Industry 4.0 advances. Up-to-date skills are essential for managing new technologies such as data administration, privacy, and cybersecurity. According to business leaders, 68 percent acknowledge skills gaps in the workforce that hinder their organizations' growth [9]. Since the onset of COVID-19, 35 percent of leaders noted that skills gaps have increased, leading to a challenge for companies with a talent pool not equipped to fill existing and new job roles [9]. In this regard, workforce education programs play a crucial role in delivering a positive impact on companies.

However, traditional education programs are not gaining enough momentum to close the widening skills gap and meet the needs of Industry 4.0. Conversely, strategically customized workforce programs that meet a business's specific needs have enormous potential. Although companies can identify skills that are lacking, they often find it difficult to link them to real opportunities. A customized workforce education program takes a strategic approach to lay out clear paths for both prospective and current employees. Sectors such as manufacturing, transportation, and retail are likely to be highly impacted by the skills gap and retraining challenge. The predictable, repetitive operational tasks associated with these sectors make them particularly suitable for two Industry 4.0 trends – automation or digitization. In Industry 4.0, approximately 60 percent of all jobs could potentially have 30 percent of their core competencies replaced by automation [9]. The emergence of robotics technologies is transforming various industries, including work machines such as mining and harbour operations, transportation such as self-driving cars and trucks, and service sectors like hospitals [10].

Knowing all this, it is clear that education needs to adapt to these changes and that is why creating a teaching and learning simulation environment for mobile robotics is a right way to do so. The goal behind the creation and development of this environment lies in the belief that it could help bridge the current skill gap and speed up the implementation of the latest solutions in manufacturing companies but the primary objective is to facilitate research, work-based training and education.

Following the introduction, the paper continues with Section 2, which describes the methods used in the process of researching the current state and trends in the field of mobile robotics and developing the planned simulation environment. Section 3 presents and discusses the obtained results and presents the integration of the desired simulation environment and its acquired equipment within a Smart Factory. Finally, Section 4 presents the conclusion together with plans for future work and research.

2 METHODOLOGY

The development of the simulation environment for the application of mobile robotics in the manufacturing industry proceeded according to the methodology shown in Figure 1, which consisted of three steps: (1) Determination of current state and trends, (2) Development of the Simulation Environment and (3) Environment integration and evaluation.

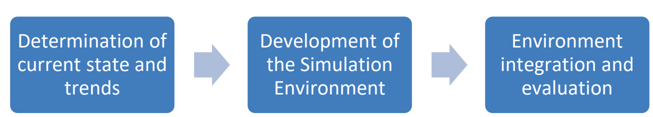

Figure 1. Methodology

2.1 Determination of current state and trends

In order to gain insight into the current state and closely examine current trends on the topic of the application of mobile robots in the manufacturing industry and achieve the objectives of this study, an analysis of existing literature has been conducted. Using the Web of Science and Scopus database of scientific and expert papers and articles, analysis has been conducted by filtering available papers using keywords such as „mobile robot“, „automated guided vehicle“, „manufacturing“, „use case“ and „case study“. Only the papers and articles from journals and conferences published in the last 5 years and written in English were considered. The articles found in the databases were combined and duplicate records were removed. The remaining articles were subsequently manually analysed to ascertain their relevance and extract desired information on the prevalent use cases of mobile robotics in the manufacturing industry, as well as the most utilized technologies for their integration. The manual analysis of papers was primarily carried out by reviewing the titles and abstracts of individual papers, and only in the case of impossibility to determine the relevance and desired information from the abstracts and titles, a more detailed review was carried out. Papers from which it was not possible to derive data on the use case or the used technologies were excluded from the analysis, while all others were included in the final results presented in more detail in the third chapter.

2.2 Development of the Simulation Environment

The objective of this study is to create a simulation environment that can serve multiple purposes such as enhancing the development of existing projects, supporting research, and promoting education in diverse use cases. To attain this aim, a forementioned determination of current state and trends was carried out to identify the required technologies and equipment. This analysis enabled the research team to identify the essential technologies and equipment that are required to develop a simulation environment that can serve multiple purposes.

In addition to the analysis of existing literature, the research team made observations in three partner companies based in Croatia. These companies provided valuable insights into their current manufacturing processes and identified areas that need improvement. By observing their processes, the team was able to identify areas where simulation could improve productivity, reduce costs, and enhance quality. Additionally, the team learned about the challenges companies face in implementing simulation technology, such as the high cost of equipment, difficulty in obtaining accurate data, and the need for skilled personnel.

Based on the findings of the literature analysis and the site visits, the research team design and develop a simulation environment which, through access to the most important technologies of mobile robotics and Industry 4.0, enables research and education in a large number of the most common use cases. The choice of used equipment and technologies was carried out in such a way as to enable the establishment of an environment that will provide the best possible research and educational conditions, despite spatial and financial limitations.

2.3 Environment integration and evaluation

In the last step, the simulation environment is integrated within the Smart Factory TLF. The integration process was carried out together with the establishment of the use case that was observed as the most frequent in the partner companies and included the establishment of different hardware and software systems and their connection. In addition to integration, the last step included the evaluation of the developed environment. The evaluation is based on informal feedback received from learners who used the system or attended training and on the basis of the lessons that can be realized within the simulation environment. To acquire the necessary data for evaluation purposes, we designed and executed a training session focused on mobile robotics and its associated technologies. Moreover, we assessed the effectiveness of the current simulation environment setup to explore potential avenues for future research and education. This involved identifying and outlining areas where further development and exploration could be pursued.

3 RESULTS AND DISCUSSION

As mentioned in the preceding chapter, the initial step involves conducting an analysis of existing literature to determine current trends and status of mobile robotics in manufacturing industry. Utilizing the Web of Science database, a total of 145 papers that incorporated the aforementioned keywords were identified. Additionally, the same search was conducted in the Scopus database, yielding a total of 359 papers for review. After eliminating duplicates and applying relevance filters, 115 papers remained for further examination and research.

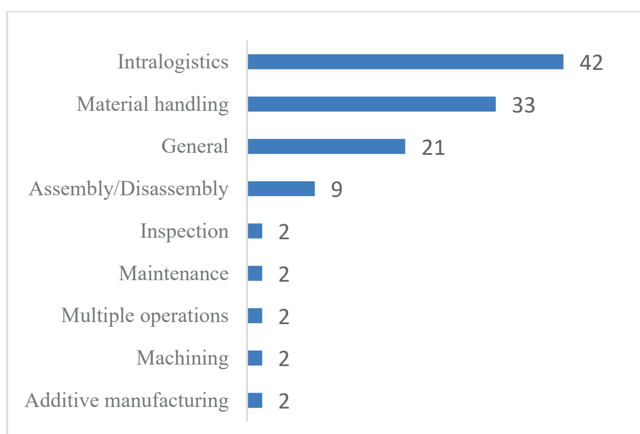

Figure 2 Types of use cases represented in literature

This research, that is, analysis was based primarily on the titles and the content of abstracts of the chosen papers. If necessary, the whole paper was read through to successfully detect and determine current trends and to find some useful and appropriate use cases and ideas to create and develop a simulation environment for mobile robotics as a part of a concept called Teaching and Learning Factory (TLF).

To begin, these 115 papers were organized based on the type of use case they presented. Among these, 42 papers were focused on intralogistics, with material handling emerging as the second most common subject. The remaining papers are illustrated in Fig 2. Further analysis was carried out on the selected literature, including titles, abstracts, keywords, and, if needed, full texts, to identify prevalent technologies and most commonly used equipment in the field of industrial mobile robotics. This analysis allowed for the categorization of technologies based on their frequency of occurrence, providing valuable insights into current trends. As depicted in Fig. 3, artificial intelligence (AI) emerged as the dominant trend, with up to 42 papers discussing and mentioning this technology. Other notable technologies included manipulator systems such as cobots and robotic arms, the Internet of Things (IoT), and more.

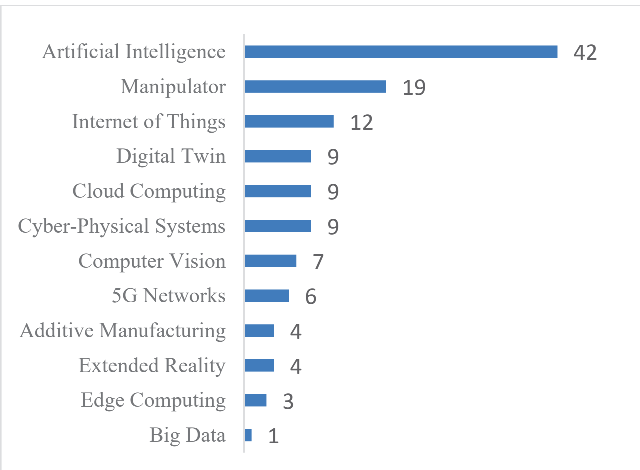

Figure 3 Share of the most used equipment and technologies

As a result of the conducted research, a few papers, i.e. use cases are worth noting and deserved a better insight for the purpose of developing the desired simulation environment. For example, in [11] a mobile robot is used as a collaborative assistant in a simulated production process where it helps the worker through four tasks at four different stations that include material handling and machine servicing without harming the human operator responsible for its supervision and for performing additional tasks. Furthermore, as seen in [12], a team of researchers and scientists from Spain, using examples from the aviation and automotive industries, developed a system consisting of an autonomous mobile platform and an autonomous mobile manipulator with two collaborative arms used for intralogistics processes, material handling, but also for tasks such as drilling and screwing. Moreover, there is an example where an autonomous mobile robot is used to take and deliver 3D printed parts and supplies to two collaborative arms whose task is to assemble a planetary gear system [13]. This is a clear illustration of how using robots in production can also save both time and money, as well as increase product quality. The experimental results also showed that the use of robots in complex assembly tasks can be beneficial and relieve human workers of repetitive and demanding tasks [13].

All things considered, to establish a fitting simulation and teaching environment and accurately identify the necessary equipment and technologies, our research team has augmented the findings from the literature analysis with invaluable insights acquired from leading companies in Croatia. As part of this investigation, the research team has observed that these companies often encounter the challenge of integrating CNC or other automated machines with manual workstations in their production processes. This presents a unique opportunity where the utilization of mobile robotics could prove highly effective in optimizing production outcomes when implemented strategically. By bridging the gap between automated machinery and manual labour through the deployment of mobile robotics, companies can unlock new levels of efficiency and productivity. The seamless integration of these robotic systems can streamline complex workflows, automate repetitive tasks, and enhance the precision and speed of production processes. The potential benefits of implementing mobile robotics in the manufacturing sector are far-reaching, ranging from improved product quality and reduced human error to enhanced workplace safety and reduced labour costs.

To try and achieve this through the simulation environment, appropriate equipment has been chosen and listed in Tab. 2. A more detailed overview of this equipment and the reasons behind choosing it are listed below.

Table 1 Equipment overview

No.	Type of equipment	Manufacturer
1	mobile robot	Robotino by Festo Didactic
2	mobile robot	Joy-IT car robot
3	Augmented Reality (AR)	Microsoft HoloLens 2
4	Virtual Reality (VR)	HTC Vive Focus 3
5	5G	telecommunication provider

1. Robotino by Festo Didactic: Robotino is a mobile robot platform developed by Festo Didactic and since it is designed for educational and research purposes and provides a flexible and versatile platform for learning and experimenting with mobile robotics, this was a great fit for the planned simulation environment. Robotino also features a mobile base with omnidirectional wheels, a manipulator arm, and various sensors for perception and navigation, making it suitable for a wide range of applications in industrial automation and robotics and even more so for simulating similar situations.

2. Joy-IT car robots: These car robots refer to autonomous or semi-autonomous vehicles used for material handling and transportation within industrial environments.

They are typically equipped with advanced navigation and perception capabilities, allowing them to navigate safely and efficiently in dynamic industrial environments. Considering these features, these car robots seemed to be a very good tool for use in the environment in question so five of them have been obtained. It is also worth noting that Joy car robots can also be used for tasks such as transporting materials, goods, or tools, and can be programmed to follow predefined paths, avoid obstacles which could, together with the Robotino and installed workstations, make for a good platform for students to get a feel of how an actual intralogistics system could work.

3. and 4. Augmented Reality (AR) and Virtual Reality (VR): In order to enhance the visualization, training, and simulation of complex tasks in industrial mobile robotics AR and VR technologies have been chosen. They are used for creating immersive virtual environments that enable exactly the aforementioned. For example, AR can overlay virtual information, such as instructions or sensor data, onto the real-world environment, while VR can create fully immersive virtual environments that replicate the real-world production floor. These technologies can be used for training operators, simulating robot operations and optimizing workflows as part of the simulation environment. The acquired AR headset is the Microsoft HoloLens 2 and the VR headset is the HTC Vive Focus 3 model.

5. 5G network: In the context of industrial mobile robotics, a robust and low-latency network connection such as the 5G is crucial for enabling real-time communication and control between mobile robots, control systems, and other devices in the production environment. 5G network also enables efficient coordination, monitoring, and control of mobile robots in industrial settings. Therefore, a partnership with the leading telecommunication services provider in Croatia has been formed and a campus 5G network installed to enable consistent connectivity, minimizing the risk of communication disruptions and ensuring uninterrupted operation of mobile robots and other devices in this simulation of the production floor. This network also supports massive device connectivity, facilitating connections to a large number of devices simultaneously. This is particularly important in industrial environments where multiple mobile robots, sensors, and other devices may need to be connected and coordinated.

Also, important to mention, three workstations have been built inside this environment and a manufacturing execution system (MES) to connect all of the above listed together has been installed.

After acquiring the necessary equipment and technologies, they were implemented inside the „Smart Factory“ TLF at the Faculty of Mechanical Engineering and Naval Architecture (FMENA) in Zagreb, and the current setup is shown in Fig. 4.

Figure 4 FMENA „Smart Factory“

The implementation of the equipment was carried out simultaneously with the establishment of a use case that simulates the use of a mobile robot to connect automatic work machines with manual workstations. This use case is seen as the most vital in partner companies, where currently workers with the help of transport carts and pallets connect machines such as laser cutters and bending machines with manual workstations where the material processing or assembly is continued. Depending on the distribution of resources within the factory floor, workers often pass through different sectors of production, which exposes them to influences such as noise or spray residue, which can negatively affect their health and safety. The establishment of the mentioned use case will enable research and education that will facilitate the automation of the described process and thus free human resources for more complex tasks with the possibility of keeping the existing layout, but also enabling flexibility in need of change. A mobile robot, an automatic production line that simulates material processing and manual workstations was used to establish the described use case. The mobile robot in this use case is used as an AGV that moves along predefined paths that are drawn inside the created 2D map of the TLF.

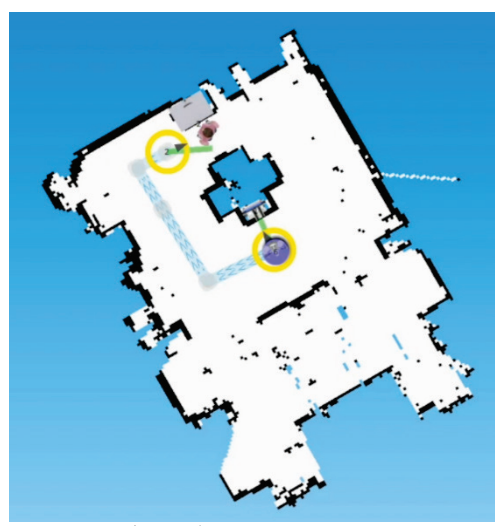

Figure 5 2D map for mobile robot navigation

The map shown in Fig.5 was created using mobile robot laser scanner, and the information about workstations and transport routes were edited manually. To ensure safe movement and obstacle detection, the mobile robot employs several sensors, including a laser scanner, an RGBD camera, and inductive proximity sensors. Additionally, precise docking on the automatic production line is supported by a combination of reflective markings and optical sensors. All resources used in the use case are connected to a manufacturing execution system (MES) that manages their work. Communication between resources and MES is enabled by wire (Ethernet) or wireless (Wi-Fi) using the OPC UA protocol, and the interaction between human workers and MES is carried out via touch-sensitive screens placed on workstations and via buttons on the mobile robot.

By simultaneously implementing the selected technologies in the TLF and establishing the required use case, a simulation environment foundation was created. This foundation enables additional research and employee education, ultimately facilitating the implementation of such systems in partner companies. The currently established base use case enables research on layout optimization, increasing the cost-effectiveness of system implementation, and education explaining the implementation methods and benefits of mobile robotics in production. In addition to student exercises and train-the-trainer education, the simulation environment has been utilized for initial training on mobile robotics in smart factories. This training was conducted as part of a scientific and professional conference, where the participants, mostly from Croatian companies, were presented with the basics of mobile industrial robotics, the method of system implementation within the Smart Factory TLF, as well as some of the available market solutions. The initial training session was attended by 39 individuals, of whom 16 (41%) expressed an increased interest in mobile robotics through active participation, while 9 (23%) of them contacted authors with additional questions about the application of mobile robotics in production processes. The current use case does not include all of the technologies that were initially acquired due to the practical challenge of acquiring and establishing all components simultaneously. However, the observed interest from the industry has stimulated further efforts towards implementing additional technologies to upgrade the existing use cases or to create new ones, thereby expanding the scope of research and education. Tab. 2 lists some of the desired directions of research and education currently being developed or planned for the near future.

Table 2 Planned Research/Education directions

No.	Research/Education direction	Description
1	5G for industrial mobile robotics	Upgrading mobile robots with 5G modules to establish a communication channel that will enable fast and stable transmission of critical information
2	AGV path planning enhanced with AR system	Using the Microsoft HoloLens 2 AR system to edit maps and control mobile robots
3	AGV fleet for intralogistics	Connecting Joy-IT mobile robots with the MES system with the aim of optimizing the planning and scheduling of their work.
4	Mobile robotics in one piece flow production	The use of mobile robotic systems within production established according to Lean principles such as one-piece flow, water spider[1] and milk run[2].

The development and utilization of a simulation environment for mobile robotics in the manufacturing industry enables research and education by making necessary technologies more accessible and promoting a work-based learning approach. Additionally, it facilitates the implementation of these systems in the industry as it allows for testing various approaches without disrupting valuable production processes. These advantages have already been observed with the current setup, and with further implementation, facilitated through collaborations with faculty students, the simulation environment will continue to serve as a platform for researching, learning, and applying the most advanced technologies for mobile robotics in the manufacturing industry.

4 CONCLUSION

In summary, this study utilized an analysis of existing literature to gain insights into the current state and trends in the application of mobile robots in the manufacturing industry. Through the analysis of articles from scientific and expert databases, the research team identified prevalent use cases, technologies, and trends in the field of mobile robotics in manufacturing. Artificial intelligence (AI) emerged as the dominant trend, followed by manipulator systems such as cobots and robotic arms, and the Internet of Things (IoT).

Building upon the literature analysis, the research team also made valuable observations in partner companies in Croatia, which provided insights into their current manufacturing processes and challenges they face. Based on these findings, the team developed a simulation environment within a TLF, aiming to enhance the development of existing projects, support research, and promote education in diverse use cases.

The simulation environment has the potential to significantly improve productivity, reduce costs, enhance quality, and provide a risk-free environment for testing and validating new manufacturing processes and technologies. It can also serve as a valuable resource for university students to gain practical experience and explore cutting-edge technologies. By bridging the gap between automated

[1] Job role responsible for efficiently moving materials, supplies, and components to the production line, ensuring that everything is readily available for the workers.

[2] Logistics concept that involves a scheduled route or circuit for collecting and delivering materials, parts, or products from various suppliers or locations.

machinery and manual labour, mobile robotics can unlock new levels of efficiency and productivity in the manufacturing sector.

Overall, this study contributes to the understanding of the application of mobile robots in the manufacturing industry and provides a framework for the development of a simulation environment that can support research, education, and practical applications in diverse use cases. Further research and evaluation of specific use cases within the simulation environment could lead to the development of effective training programs and new concepts that could be implemented in the industry. Specifically, this learning factory will be used in the near future to develop a digital water spider which could prove to be a very useful tool in the context of lean manufacturing.

5 ACKNOWLEDGMENT

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CREATING AN INTEGRATED PUBLIC TRANSPORT NETWORK FOR URBAN TRANSIT IN THE CITY OF VARAŽDIN

Ante KLEČINA, Ljudevit KRPAN, Krešimir BUNTAK, Ivan CVITKOVIĆ

Abstract: The city of Varaždin is struggling with street traffic that has been piling up for years. The city has been tackling this problem by issuing strategic plans and performing transport surveys. One such survey was undertaken in 2022. From that surveys a huge gap can be observed between the citizens who are willing to use public transport system and the actual number of citizens that use the system. The surveys discovered poor timetables with poor routing of the lines and poor connectivity among them. The possible solution to this problem was to create a new integrated public transport network, with good routing, good coverage of the city area and a timetable with adequate frequencies. Such timetables offer full connectivity among all the lines in the system therefore forming full accessibility of city through the entire day. This was the first effort to form such efficient network for Varaždin.

Keywords: public transport, urban transit, integrated public transport, timetables, routing, public transport network

1 INTRODUCTION

Public transport in the city of Varaždin is being carried out by Čistoća d.o.o. This is the city company for utilities and it also acts as a licensed public transport operator.

Varaždin is a city in northern Croatia, with the population of 43.782 [1]. It is the capital of the Varaždin County with the population of 159.487 [1]. Its wider metropolitan region can be estimated around 100.000 people.

Highest share in transportation modal split in the city is by car, while strategic documents, like European Green Deal [2] set goals like reducing the CO_2 emissions from transport by 90% by 2050. This will, among all other activities, have to be achieved by expanding the usage of public transport, walking and cycling, while simultaneously reducing the usage of automobiles.

The authors, while conducting research activities in the city of Varaždin, noticed the problem, that the modal share of public transport usage, especially its segment of urban city bus public transport system, is low and far away for strategic goals. The second part of the article gives a literature review on integrated synchronised timetable solutions. In part three a short history and the legislative basis for conducting the public transport systems in Croatian cities was given. Part four gives the analysis of the current public transport network in the city, its timetables, the overall modal share, and it also gives insight into the results of the survey carried out among the citizens of the Varaždin region. In part five the authors give the ideas on how to tackle the noticed problem of low usage of the public transport system. A suggestion for a new integrated, well-routed and user-friendly network is given and elaborated there. In part six, a short set of guidelines was given on how to apply the suggest improvements for the city of Varaždin to other similar cities and towns in Europe.

This article uses parts of the survey carried out in the city of Varaždin for the purpose of making the study of Evaluation of the Sustainable Urban Mobility Plan of the City of Varaždin [3].

A following hypothesis is being tested in this paper: H1 – More than half of the citizens in the city of Varaždin and the surrounding region would use a high-quality public transport system if such system was available to them.

2 LITERATURE REVIEW

Other authors have written about the importance of integrated synchronised timetable and well-planned networks before in order to reach the attractiveness of the public transport system for the passengers.

Nielsen and other [4] said that when the aim is to compete with the motorcar for travel in urban regions two crucial qualities of the system are: short waiting times between departures; and an integrated network of services between all areas of significant transport demand. A system without these two qualities can never be a real competitor to the car as the main mode of transport.

Therefore, network planning must find ways to concentrate resources to a sufficient number of high frequency lines that form a travel network that caters for a major part of the demand for motorised transport in the city region [5]. Smoliner and Walter [5] concluded this after looking into the data from three cases of regional railways in Styria, Austria, and several cases of regional railways in Czech Republic.

The structure of lines in the network can significantly affect the efficiency and attractiveness of the public transport system. Some principles for the development of an efficient and attractive network should be considered [6]:

Fast and punctual operations at the highest possible speed of service are a key factor. The operational speed determines both the cost efficiency and the attractiveness of the public transport system. A high-quality public transport system cannot make many compromises on this aspect of the service. Geißler [6] concluded that according to the data that was gathered by the survey which was the part of the EU project USEMobility. The project investigated real reasons why people use public transport instead of their cars. The survey was carried out in 6 European countries, including more than 10.000 people.

When fast and reliable routes are established all over the city, the network should be developed with as few, continuous and high frequency lines as possible. In general, pendulum lines should be preferred. They create more opportunities for direct travel and will normally also achieve better use of the transport capacity offered. But they require a high level of priority on the route.

The pendulum principle is applicable not only in relation to the city centre and the rest of the inner city. It should normally also be applied to suburban centres and feeder lines to railway stations and other public transport interchanges in the outer parts of the city. With reliable and undisturbed operations, it will also be possible to synchronise the timetables of different lines running along the same route.

Smoliner and Walter [5] concluded that Integrated periodic timetables (known as ITF, short for German "Integrierter Taktfahrplan"), are perfectly suited for the needs of countries with many small cities in comparably close distances. (…) Furthermore, most railway passengers are travelling in regional and local railway networks. Integrated periodic timetables (ITF) offer optimal connections in a network and transfer times are short. Therefore, the integrated periodic timetable allows for a high network-wide benefit for customers and represents the optimal solution for medium-sized countries. However, a joint planning of long-term timetable and infrastructure development is essential [5]. Although the authors are talking about the railway systems, these conclusions can be applied to local bus networks as well.

According to Geißler [6] In most cases public transport authorities have direct influence on timetables. When defining requirements, public transport authorities should pay special attention to this issue. One of the most effective measures to optimise the services offered and the flexibility of use is the introduction of integrated synchronised timetables (clock-face schedule).

An integrated synchronised timetable or clock-face timetable is a concept where public means of transport run at consistent intervals (e.g. every two hours or every hour or every 30 minutes etc.). This means that the minute of departure (as well as the minute of arrival) for a given service is the same every hour. Timetables based on this principle contribute significantly to the flexibility of use, as services are offered at regular intervals all day, not only during peak hours. They are easier to memorise for passengers because departure times repeat themselves in a regular rhythm. Furthermore, connections to other services are the same all day, as their departure times also repeat themselves.

3 HISTORY AND CURRENT OPERATIONS IN CITY'S PUBLIC TRANSPORT SYSTEMS

This part gives a short historic overview of public transport in the city of Varaždin. It also gives a short insight into the regulations and acts that are a legislative base for organising and conducting of public transport in the city.

3.1 Historic overview of urban public transport in the city of Varaždin

Urban public transport in the city of Varaždin, the one organised within the city limits together with or without surrounding municipalities first started in Varaždin in 2006 [1]. The city council issued a Resolution on giving the concession for city public transport of passengers on the territory of the City of Varaždin [7]. The company IM EX Car Ltd got a 10-year concession. The company ended in financial difficulties and the concession was then awarded to Autobusni prijevoz Varaždin in 2011 [8, 9]. This company was bought by Presečki grupa in 2015, but due to transferring the assets to another company it lost its right to the concession given by the City of Varaždin. The next concession was awarded to Vincek Ltd in 2016 [10, 11]. The city council in 2021 awarded the concession for public transport in the city of Varaždin to Čistoća Ltd [12] which started operating the lines on October 1st in 2021 [12, 13]. Čistoća is a public company, 100% owned by the City of Varaždin. All the companies that had the concession before Čistoća were privately owned.

Urban public transport was not organised in the city form the time Croatia got its independency in 1992 until 2006. There were no data found by the authors on any attempt to organise the public transport within the city limits before 1992 either.

3.2 Legislative bases for organising public transport in Varaždin and its region

In Varaždin County, where Varaždin is the capital of the County, public transport is organised based on several legislative documents.

The Regulation (EC) No 1370/2007 of the European Parliament and of the Council of 23 October 2007 on public passenger transport services by rail and by road is [14] a lex specialis when it comes to regulation, awarding and subsidising the public transport operations in the European Union. The regulation strictly states that public transport awarded in accordance with this regulation can be subsidised and such grants of financial compensation are considered as income for the transport operator. The contracts which concluded between public authorities and the operators, which are in accordance with this Regulation, are called Public Service Obligation Contracts. If any other public transport services, meaning the ones not regulated by Public Service Obligation, are being subsidised, then the general regime for State aid should apply, with all its limitations to conduct business.

The Act on transport in road traffic [15] is a national act which regulates international, intercounty, county and communal (city) road transport.

The Act on communal activities [16] is a national act that regulates managing and financing of communal activities, communal infrastructure and other important issues of communal activities.

The Act on railways [17] is the national act that, besides other, covers awarding the Public Service Obligations contracts to railway operators. Although it is planned, according to Master plan for integrated passenger transport [18], the integration and the harmonization of the transport services with the railways is not in the scope of this paper.

The City of Varaždin currently has a concession contract with Čistoća Ltd [12]. According to the Regulation 1370/2007 [14] the City should have concluded a Public Service Obligation contract with Čistoća before December the 3rd 2019[1].

4 THE ANALYSIS OF THE PUBLIC TRANSPORT NETWORK, TRAVELLING HABITS AND TRAVELLING PREFRENCES

This article uses data from the survey carried out during the development of the study called Evaluation of the Sustainable Urban Mobility Plan of the City of Varaždin [3]. The parts that cover the problems of the existing public transport in the city of Varaždin and the surrounding area were used the most.

This part covers the analysis of the public transport network, citizens mobility and traveling preferences.

4.1 The analysis of citizens mobility in Varaždin and the surrounding region

The citizen mobility was analysed with an online questionnaire among citizens in Varaždin and the surrounding area. The overall number of respondents was 333.

The traffic count was carried out on 12 locations around the city of Varaždin from 6:00 to 8:00, 10:00 to 12:00 and 14:30 to 16:30 hours.

Public transport passengers were counted on the main railway station in Varaždin, from 5:00 to 16:00 hours and on the main bus station in Varaždin, from 5:00 to 17:00 hours.

Passengers on all five (from 1 to 5) lines on urban city bus systems were counted from 5:00 to 17:00 hours.

The overall result can be observed from passenger modal split made for the city of Varaždin. Modal split is shown in the Table 1.

Table 1 Modal split of the passenger transport in the city of Varaždin during workdays, January, 2023. (made by authors).

Transport mode	Automobiles	Bicycles	Pedestrians	Urban City Bus	County Local Bus	Trains
Passenger kilometres	156.640	1.620	4.875	1.624	11.968	11.201
Modal share	83,35%	0,86%	2,59%	0,86%	6,37%	5,96%

Figure 1 shows the graph of the passenger modal split in the city.

Modal split shows a low ridership of the city's public transport system, the Urban City Bus of only 0,86%. The usage of the County Local Buses and Trains is higher, 6,37% and 5,96%, but these systems carry passengers from the surrounding region to the city and it doesn't transport people among urban destinations.

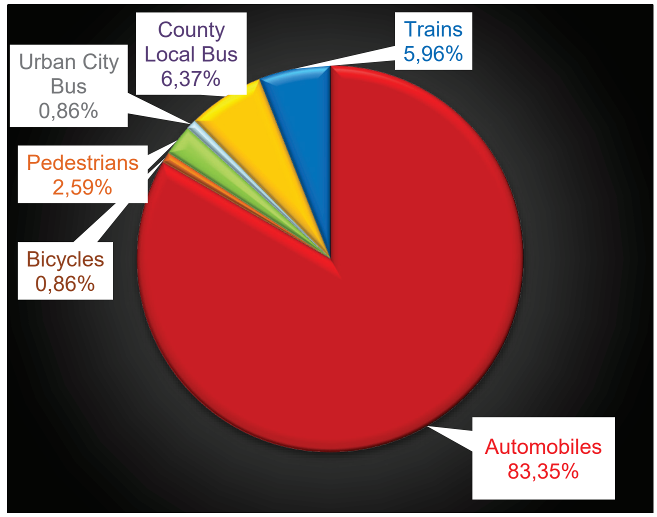

Figure 1 Modal split of passenger transport in the city of Varaždin during workdays, January, 2023. (made by authors).

4.2 The analysis of the public transport network

The analysis of the public transport network was done by mapping the existing lines and calculating the connections among the lines. The connections among the lines are very important in order to reach the accessibility of the public transport system as high as possible.

The route of the Line 1 can be seen at Figure 2.

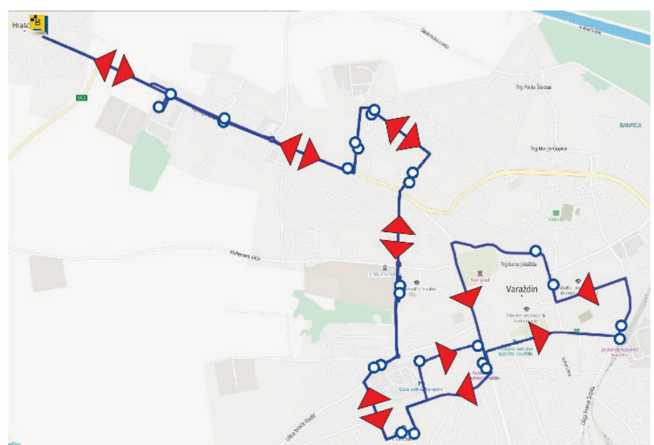

Figure 2 The routing of the Line 1 in Urban City Bus system in Varaždin (made by authors using the HAK Interactive maps [19]/Mireo Maps [20]).

When observing the route of the line 1, it was seen that rooting was not adequately designed. Comparing the geographic positions of the stops and the timetable for the line [21, 22], several anomalies were detected:

- The distance from Ulica Eugena Kumičića 9/A to Trg Bana Jelačića 9 stop can be covered by bus in 18 minutes and by foot in 15 minutes [23],

[1] According to the Regulation 1370/2007 [8], on December the 3rd 2019, a twelve-year adjustment period had ended.

- The distance between Gradski kolodvor stop to Ulica Petra Preradovića 15 stop can be covered in 3 minutes, however, the return journey takes 56 minutes, or more,
- The distance between Gradski kolodvor stop and Ulica kralja Tomislava 8, Hrašćica, the last stop on the line, takes 26 minutes by bus and only 8 minutes by car [23].

The route of the Line 2 can be seen at Figure 3.

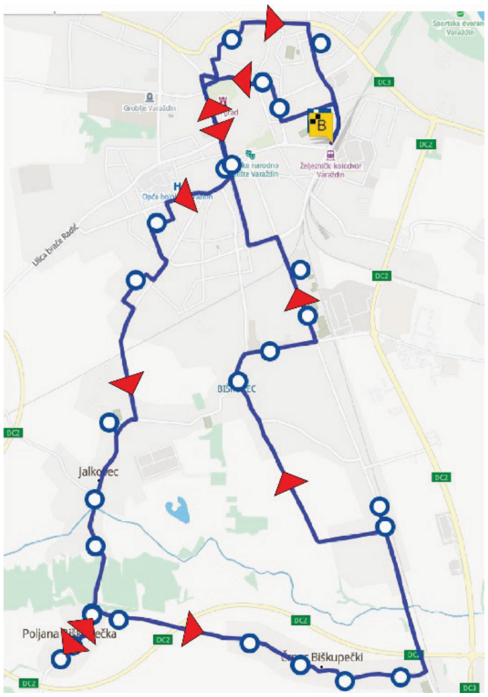

Figure 3 The routing of the Line 2 in Urban City Bus system in Varaždin (made by authors using the HAK Interactive maps [19]/Mireo Maps [20]).

When observing the route of the line 2, it was seen that rooting was not adequately designed. Comparing the geographic positions of the stops and the timetable for the line [21, 22], several anomalies were detected:

- The line is designed as circle line on most of its route; this potentially offers good traveling times between many stops while the return trips take much longer times in comparison with first trip,
- The trip from Šibenska ulica 10 stop to Ulica Braće Radić 52/E, Jalkovec takes one minute, while the return journey takes 59 minutes, for some departures even more,
- Such anomaly, like the one in the bullet point before, was detected for at least 22 stops from 28 stops on the route,
- The trip from Ulica Petra Preradovića 15 stop to Zagrebačka ulica 85/A stop takes 32 minutes by bus while it takes 22 minutes by foot [23],
- The trip from Ulica Petra Preradovića 15 stop to Zavojna ulica stop takes 42 minutes by bus while it takes 13 minutes by foot [23].

The route of the Line 3 can be seen at Figure 4.

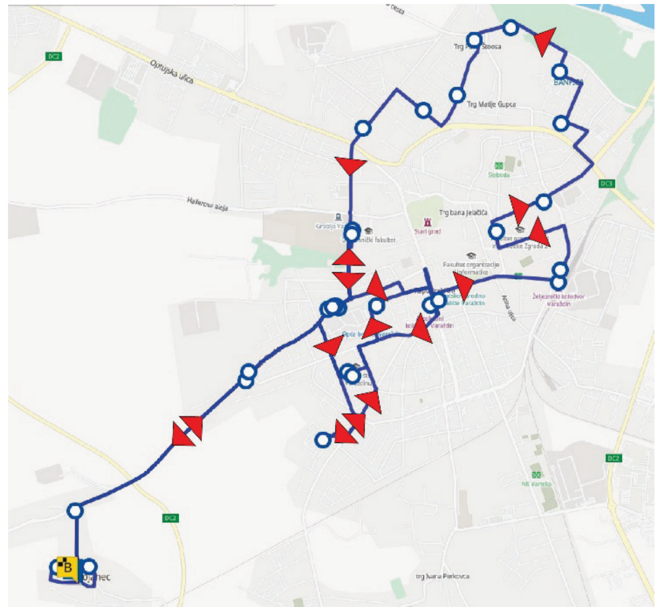

Figure 4 The routing of the Line 3 in Urban City Bus system in Varaždin (made by authors using the HAK Interactive maps [19]/Mireo Maps [20]).

When observing the route of the line 3, it was seen that rooting was not adequately designed. Comparing the geographic positions of the stops and the timetable for the line [21, 22], several anomalies were detected:

- The line is partly circular in the northern part of the city of Varaždin, this makes traveling between certain stops short, but the take unusually long in the opposite direction,
- The trip from Ludbreška ulica 70 stop to Dravska ulica 32 stop takes one minute, while the return journey takes 59 minutes, for some departures even more,
- The trip from Braće Radića 50 stop to Ulica Zvonimira i Vladimira Milkovića 31 stop takes 7 minutes by bus while it takes 5 minutes by foot [23],
- The line stops at Braće Radića 50 stop four times for every individual departure.

The route of the Line 4 can be observed at Figure 5.

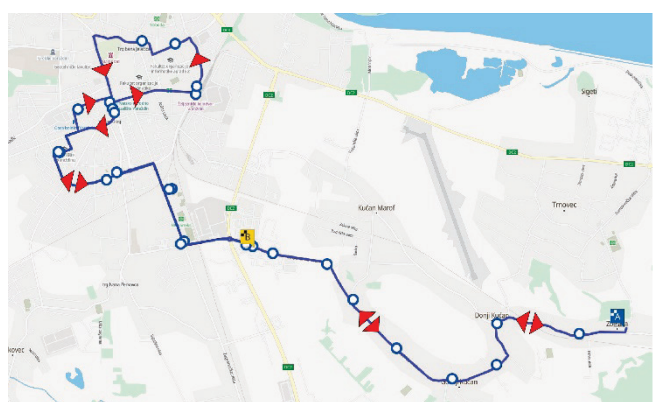

Figure 5 The routing of the Line 3 in Urban City Bus system in Varaždin (made by authors using the HAK Interactive maps [19]/Mireo Maps [20])

This line does not show minor anomalies. It is mostly radial with acceptable routing. The anomalies noticed are the following:

- The trip from Zagrebačka ulica 85/A stop to Gradski kolodvor stop takes 16 minutes by bus and 17 minutes by foot [23],
- The route takes a partial route that is circular in the city centre, covering stops like Petra Preradovića 15 and Trg Bana Josipa Jelačića 9 on the returning trip, while these stops are not being served during the departure from the first stop Varaždinska ulica 119, Zbelava. Two out of eight departures during the day terminate Gradski kolodvor, therefore excluding the possibility of the return trip for the two mentioned stops, but the similar problem has been observed with other lines serving these two stops.

If we observe the Gradski kolodvor stop as a terminal stop, it takes 26 minutes from Varaždinska ulica 119, Zbelava stop and 29 minutes to this same stop. The same trip by car would take at least 12 minutes [23].

The route of the Line 5 can be observed at Figure 6.

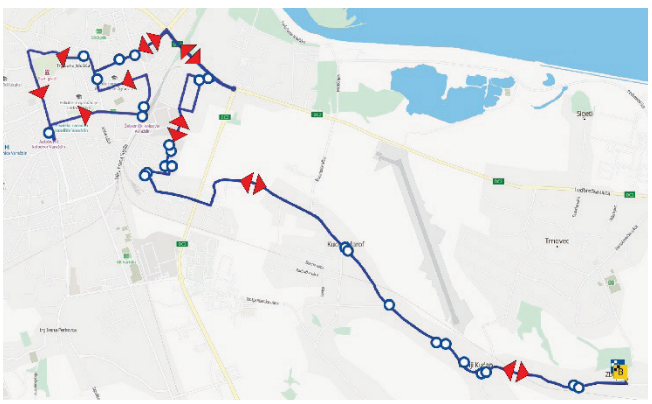

Figure 6 The routing of the Line 3 in Urban City Bus system in Varaždin (made by authors using the HAK Interactive maps [19]/Mireo Maps [20]).

The Line 5 also does not show many anomalies.

This line also suffers from partly circular route in the city centre, which causes that the trip from the first stop in Zbelava to Gradski kolodvor stop takes 29 minutes while the return trip takes 18 minutes.

Table 2 shows the overall number of passengers recorded on each line per workday. The passengers were counted from 5:00 to 16:30 hours, which covered more than 80% of the departures.

Table 2 Number of passengers in the Urban City Bus system in the city of Varaždin during workdays, January 2023. (made by authors).

Line Number	1	2	3	4	5	Overall
Passengers per day	142	78	39	92	55	406

Table 3 shows the overall number of return trips on each line per every workday, on Saturdays and Sundays and holidays.

Table 3 Number of return trips in the Urban City Bus system in the city of Varaždin during workdays, Saturdays, Sundays and Holidays, January, 2023. (made by authors).

Line Number	1	2	3	4	5
Departures on workdays	8	8	8	8	8
Departures on Saturdays	6	6	6	6	6
Departures on Sundays and Holidays	0	0	0	0	0

Table 3 shows the number of departures. Overall number of 8 departures per workday does not provide a satisfactory level of service for urban transit. The absence of service during Sundays creates a gap in the mobility offer.

Table 4 shows arrivals and departures from the station/stop called Gradski kolodvor, which serves as a central point to the system, because all the lines serve this station/stop. It a small terminal that can accommodate 6 to 7 medium M2 category buses.

Table 4 Arrivals and departures in the Urban City Bus system in the city of Varaždin during workdays, January, 2023. (made by authors).

Line 1	Time of arrival	6:34	7:34	10:34	12:34	15:14	16:34	17:29	20:24
	Time of departure	6:34	7:34	10:34	14:06	15:14	16:34	17:29	20:24
Line 2	Time of arrival	5:55	6:55	7:55	10:55	12:55	15:00	16:00	17:20
	Time of departure	5:05	6:05	7:05	10:05	12:05	14:10	15:10	16:30
Line 3	Time of arrival	6:13	7:13	8:25	10:23	12:23	13:43	15:03	19:08
	Time of departure	6:13	7:13	9:13	10:23	12:23	13:53	15:03	19:08
Line 4	Time of arrival	5:46	6:41	7:36	12:26	13:21	15:21	18:36	20:21
	Time of departure	5:46	6:41	10:36	13:26	14:21	15:21	18:36	20:21
Line 5	Time of arrival	5:49	6:44	8:08	9:54	10:44	14:27	15:32	19:37
	Time of departure	5:49	6:44	8:08	9:54	10:44	14:27	15:32	19:37

The analysis of the table 4 shows that the timetable is not integrated, and it does not provide the possibility for the passengers to change (transfer) between any two lines. Therefore, it does not provide the accessibility of the entire city and passengers can only make return trips on one line only, without the possibility to change. All arrivals and departures from line 1 to 3 are all more than 10 minutes apart. Arrivals and departures of the lines 4 and 5 are only 3 minutes apart, but passengers can always change from line 4 to line 5 but the vice-versa combination is not possible. Hence, combining of lines 4 and 5 does not offer the possibilities of return trips, just one-way trips.

4.3 The analysis of travelling preferences in Varaždin and the surrounding region

During the surveys for the Evaluation of the Sustainable Urban Mobility Plan of the City of Varaždin [3] a questionnaire was given to citizens of Varaždin and the surrounding region. Overall number of respondents was 333.

Several questions regarding public transport were chosen to be analysed in this paper.

The first question analysed was “The frequency of the public transport is high and the waiting times on public transport stops are acceptable”. The Figure 7 shows the answers given by citizens.

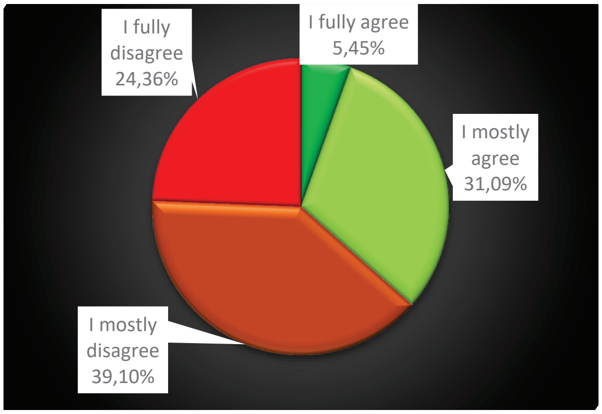

Figure 7 “The frequency of the public transport is high and the waiting times on public transport stops are acceptable”, city of Varaždin and surrounding regions, n=312 (made by authors).

The results shown at Figure 7 show most of the citizens are not satisfied with the frequency and waiting times in public transport systems. This indicates that frequencies on lines are to low.

In the questionnaire there was also a following question: “If there was a public transport system available, where every citizen could use common tickets for both trains and buses (local and regional public passenger transport, for city and the county), with harmonized timetables of train and bus lines, with easy changes among train and bus lines, where a good network with full coverage of the region exists (like Varaždin or the city with the surrounding region), where departures were available at least every hour from early morning until late in the night and if such system was financially affordable, would you travel differently and use public transport?” In short, this can be reduced to a shorter question like “Would you use a high-quality public transportion system?”

The results can be observed at Figure 8.

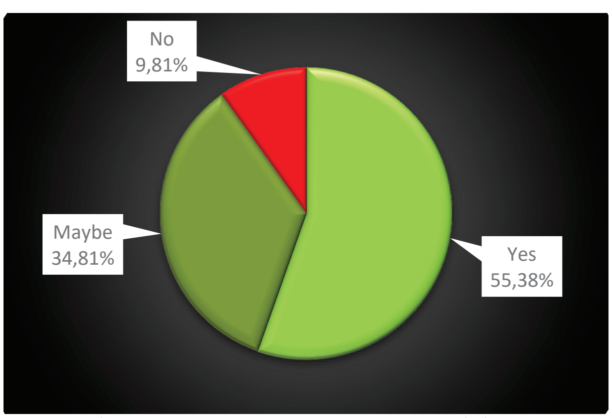

Figure 8 “If there was a public transport system available (…) where a good network with full coverage of the region exists (…), where departures were available at least every hour from early morning until late in the night and if such system was financially affordable, would you travel differently and use public transport?”, city of Varaždin and surrounding regions, n=316 (made by authors).

Next question just after the one mentioned above was: “To what extent would you use such a system?”

The results can be seen at Figure 9.

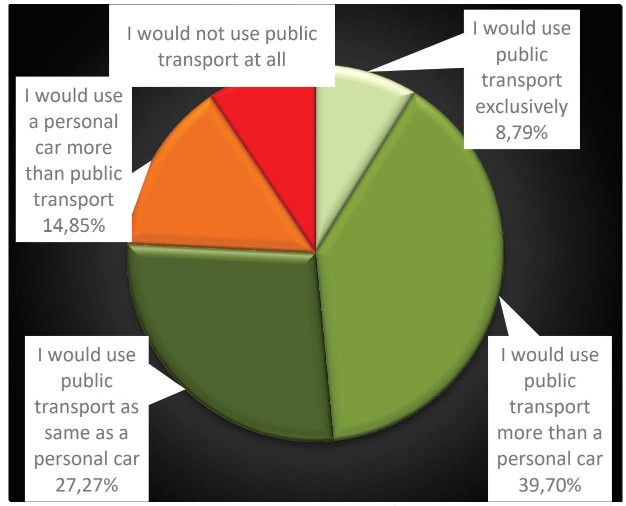

Figure 9 “To what extent would you use such a (high-quality public transport) system?”, city of Varaždin and surrounding regions, n=330 (made by authors).

The answers of the citizens show that there is more than 90% of them that are willing to use a high-quality public transport system if such was available. Only 9,81% respondents said that they would not use such system.

Accordingly, 75,76% of the respondents said that they would use such public transport system as same as the car or more than the car.

5 THE SUGGESTED SOLUTIONS FOR IMPROVEMENT OF RIDERSHIP IN PUBLIC TRANSPORT SYSTEM IN THE CITY OF VARAŽDIN

This part explains the observed public transport gap in the public transport system in the city of Varaždin. A suggestion of an integrated, well-routed and user-friendly public transport network for the city was also suggested in this part.

5.1 The public transport gap

When a comparison with the results from the passenger count and from the results for the questionnaire is made, it can be observed that a gap exists from the actual usage of public transport and from the wishes or preferences of the citizens to use an accessible and high-quality public transport system.

Modal share of the City Bus System is only 0,86%, County Local Buses 6,37% and trains 5,96%. On the other hand, the share of the automobiles is 83,35%. Also, 36,54% of the citizens fully or mostly agree that the frequency of the public transport is high and the waiting times on public transport stops are acceptable.”

The results show in Figure 8 and Figure 9 show that accessible and high-quality public transportion system would be their preferable choice of transport for most of the citizens.

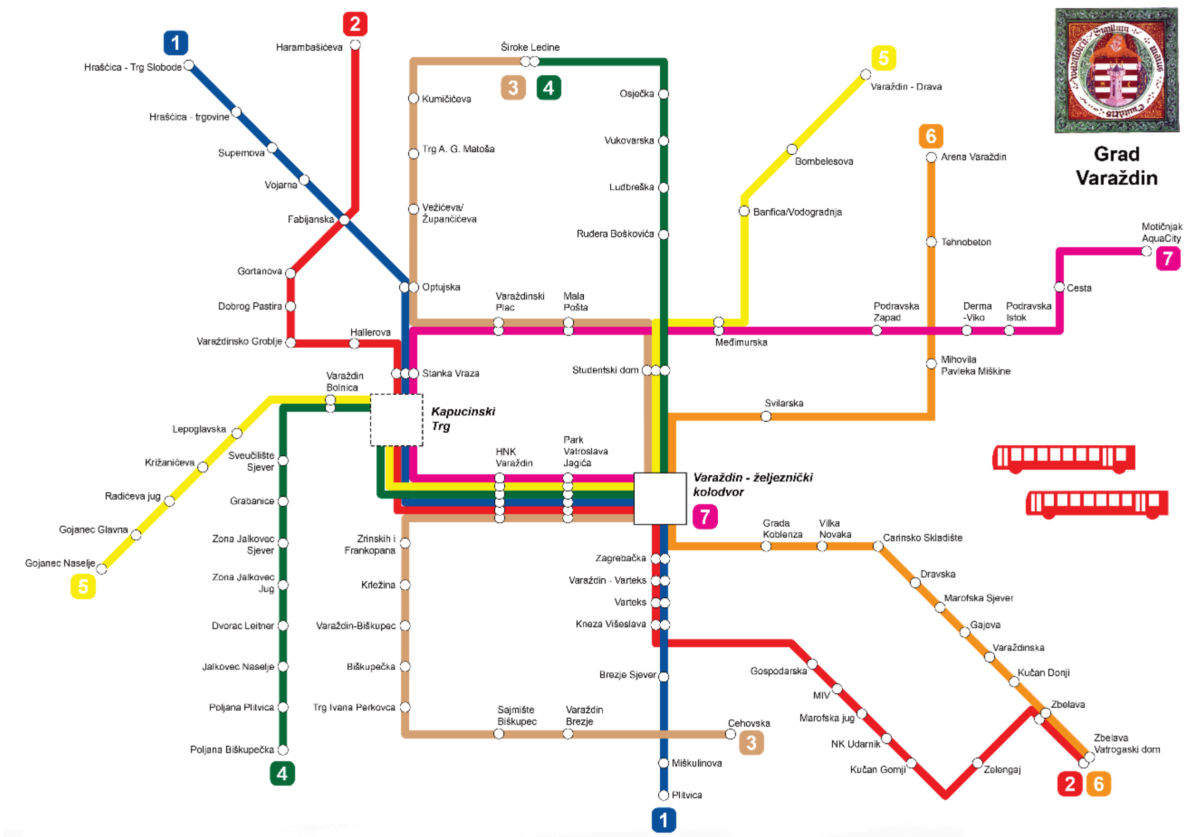

Figure 10 New suggestion of a schematic, integrated, well-routed, user-friendly urban city bus public transport network for the city of Varaždin (made by authors).

Such results suggest that a large gap from the current public transport offer and the public transport demand exists. They also suggest a large potential for using of an accessible and high-quality public transport system if the one would have been available.

5.2 New public transport network for the city

In order to eliminate the established public transport gap in the future, a new public transport network for the city of Varaždin was created. The routing of these new lines was done in order to offer the optimal operating (commercial) speed on all the lines. All the lines meet at the main terminal "Varaždin – željeznički kolodvor". This point is also a station/stop in the existing system with the name Gradski kolodvor.

A new suggestion for public transport network can be observed at Figure 10. This suggestion cannot be implemented right away due to the need to implement certain changes in the traffic network. There should be some new stops built and furnished, while certain streets also need certain rearrangement of regulation of traffic. Before implementing the proposal at Figure 10, a solution that could fit the existing traffic and transport infrastructure could also be designed, while respecting the guidelines to produce a well routed, integrated and user-friendly public transport network.

The suggestion shown at Figure 10 is done as a schematic map, with the emphasis on user-friendly approach, designed in the way that is easy to interpret by most of the users. The users can find key information to plan their journey. They can find the stop to enter the system, station to change between the lines, if necessary, and the stop to exit the system. The lines were made as diametrical lines. According to Vuchic [24] diametrical lines connect suburbs on different sides of the city centre. They follow radial directions, passing through the central area.

5.3 New integrated timetable for the public transport system in Varaždin

The network suggest at Figure 10 is designed to be used with an integrated timetable, meaning that the timetable offers the possibility to change between any two lines in the system. The change can be done at the station that is the point of integration in the system. Combining an integrated network with an integrated timetable offers the possibility for every user to reach any stop (destination) in the system with not more than one change.

In high-frequency systems, meaning the frequency of departures on every line in the system is every 10 minutes or less, harmonising the timetables is not needed. In such case, only infrastructure capacity is needed to accommodate the passengers waiting to make the change.

The system shown at Figure 10 is a low frequency system. In low-frequency system, meaning that departures on every line are more than every 10 minutes, more like every 30 minutes or every 60 minutes, harmonization of timetables is necessary in order that users can make the change needed to continue their journey.

An example of a harmonized timetable is shown in tables 4. The example shows the integration between 6:05 hours and 6:13 hours.

Table 5 Arrivals and departures for station Varaždin-željeznički kolodvor, suggested for the new urban city bus public transport system between 6:05 hours and 6:13 hours (made by authors).

Line number	1		2		3	
Direction	**A**	**B**	**A**	**B**	**A**	**B**
Arrival	6:05	6:06	6:05	6:06	6:05	6:06
Departure	6:12	6:13	6:12	6:13	6:12	6:13

Line number	4		5		6		7
Direction	**A**	**B**	**A**	**B**	**A**	**B**	**A**
Arrival	6:07	6:08	6:07	6:08	6:07	6:08	6:07
Departure	6:13	6:14	6:13	6:14	6:13	6:14	6:13

This timetable, meaning arrivals and departures on all lines, can be repeated every 30 minutes or every 60 minutes. Therefore, every departure offers the possibility for the users to change between the lines throughout the entire day.

6 RECOMMENDATIONS TO USE SIMILAR APPROACH FOR OTHER MEDIUM AND SMALL SIZED CITIES

The solutions mentioned here in parts 5.2. and 5.3. can be applied for similar cities and their surrounding regions of similar size.

The most important steps that need to be undertaken are:

- To design a network of lines with routes of the lines which are well routed, in order to offer attractive travelling times; guidelines on how to design an attractive network of lines was given by Nielsen et al. [4],
- To establish one or more Transit centres [24] or Main terminals [24] in the network, where passengers can change between any two lines in the system,
- To design an integrated clock-face timetable for the system, with enough dwelling time for all the public transport vehicles at the Main terminal to allow the passengers enough time to change between any two desired lines,
- To design a timetable with frequencies of departures that are attractive to users, which are at least every 60 minutes or less [6].

7 CONCLUSIONS

High-quality public transport systems should be designed and operated in the cities in order to reach strategic transport goals and climate goals also. A huge shift from automobiles to the alternatives, like public transport, walking and cycling must be done in all the EU countries.

The urban bus city public transport in the city of Varaždin begun in 2006. No previous records of similar systems in history were found by the authors. From 2021 the concessions are no longer given to private operators, while a publicly owned transport operator Čistoća Ltd started to provide public transport in the city the same year.

Together with the problem of a small modal share of the public transport in Varaždin, the analysis discovered that urban bus city lines suffer from certain anomalies, the biggest being the one regarding poor routing of all the lines in the current systems. Such system does not allow for the users to change between certain lines and departures in the system, thus significantly lowering its overall accessibility and traveling possibilities.

On the other hand, the survey also discovered that citizens are quite keen on using high-quality public transport system if such was available. Only 9,81% respondents would not use such system. The others were more receptive, 34,81% said they would maybe use the system, while 55,38% said yes to using the system. Accordingly, 75,76% of the respondents said that they would use such public transport system as same as the car or more than the car.

These findings can test the hypothesis given in the introduction: "H1 – More than half of the citizen in the city of Varaždin and the surrounding region would use a high-quality public transport system if such system was available to them." The hypothesis can, therefore, be confirmed.

In order to tackle the current low ridership in the system, a new schematic, integrated, well-routed, user-friendly urban city bus public transport network was created. Such network is designed to be used together with an integrated timetable. These two elements can offer a high-quality public transport system. Such system might attract more people for more trips in order to extend the modal share of public transport systems in the city and also in the surrounding region.

Similar systems can be developed and implemented in most of the medium and small sized cities in Europe.

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A Dynamic Systems Model for an Economic Evaluation of Sales Forecasting Methods

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Sales forecasts are essential for a smooth workflow and cost optimization. Usually, they are assessed using statistical error measures, which might be misleading in a business context. This paper proposes a new dynamic systems model for an economic evaluation of sales forecasts. The model describes the development of the inventory level over time and derives the resulting overstock and shortage costs. It is tested on roughly 3,000 real-world time series and compared with the commonly used approach based on statistical measures. The experiments show that different statistical measures have no coherent evaluation, making their usage even less suitable for a practical economic application.

Keywords: *Forecasting, Inventory Management, Sales Forecast, Supply Chain Analytics, Time SeriesLogistics*

Development of Augmented Reality Technology Implementation in a Shipbuilding Project Realisation Process

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The technology of Augmented Reality (AR) is taking on an increasingly important role in the digital (and green) transformation of industry, including shipbuilding. Upgraded to the three-dimensional (3D) ship model in the form and content of a Digital Twin, (industrial) AR contributes to the activities of sale and marketing, development, and design, as well as production and maintenance. Recognizing its leading potential in creating the configuration of Shipyard 4.0, research on the further applicability of AR in shipbuilding processes, with an emphasis on outfitting activities, was initiated in collaboration between industry and universities. The paper describes the course of research and development of an AR application supportive to the shipbuilding process. The authors emphasize the possibility of achieving savings in the shipbuilding project realization by implementing the AR application pursuant to conducted proof of concept, thus contributing to the shipbuilding system competitiveness improvement.

Keywords: *Augmented Reality, Digital Twin, Shipyard 4.0, proof of concept, competitiveness.*

Towards Logistics 4.0: A Skill-Based OPC UA Communication between WMS and the PLC of an Automated Storage and Retrieval System

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In order to bring intralogistics systems to the same level of interoperability as today's modern production systems, logistics must take the essential steps towards Industry 4.0. This requires an increasing abstraction level of control logic as an enabler for horizontal and vertical integration. The abstraction will lead to the interconnection of manufacturing and logistics control with the production planning and warehouse management systems (WMS). A main enabler for these communication paths are service-oriented architectures (SoA). OPC UA has established itself as a widely used and already adopted SoA-based communication standard in industry.

The paper describes the realization of an OPC UA-based approach for the communication between a WMS and a PLC of an automated storage and retrieval system (ASRS). The conceptual basis of communication design are skills of the ASRS. The work is supported by an architectural design with a subsequent prototypical implementation.

Keywords: *Control Logic; Industry 4.0; Logistic System; OPC UA; Skill-based Engineering*

OPERATIONAL AVAILABILITY PREDICTION FOR A FLEET OF LARGE SYSTEMS; AN APPROXIMATE SOLUTION

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Abstract: We consider a fleet of systems (e.g. a fleet of aircraft of a certain model) which are returned to operational status by exchanging an easily replaceable unit on site or nearby (provided that an identical unit in good condition is available). Such units are called LRUs (on Line Replaceable Units). These LRUs must be exchanged by qualified personnel who are multi-skilled but not experts in the internal functioning of the different types of LRUs, and this in a relatively short time (a few hours at most). The major goal of this study concerns the number of systems blocked by unavailability of spare LRU (in the form of the probability distribution or expectation of this variable). The explosion in the number of states required for some real-world applications limits the use of a classical Markovian approach to model and evaluate the performance of fleet systems. This is the reason why we propose here an approximate recurrent method to calculate the operational unavailability. Its low relative complexity allows it to be used for applications encountered in the maintenance domain. Although approximated, the method provides the result with a small relative error, ranging from 10^{-2} to 10^{-8}. Although generally less significant, the downtime associated with disassembly and reassembly is also taken into account in this study.

Keywords: Performance evaluation, Integrated logistic system, Stock shortage, Line replaceable unit, Operational availability, Intrinsic availability, Proactive queues, Non product-form queueing network.

1 INTRODUCTION

We consider a fleet of systems (e.g. a fleet of aircrafts of a certain model) which are returned to operational status by exchanging an easily replaceable unit on site or nearby (provided that an identical unit in good condition is available). Such units are called LRUs (on Line Replaceable Units). These LRUs must be exchanged by qualified personnel who are multi-skilled but not experts in the internal functioning of the different types of LRUs, and this in a relatively short time (a few hours at most). These time and skill constraints mean that LRUs are generally large and expensive subsystems (such as an aircraft engine). After the exchange, the defective LRU is directed to a repair center where it is either brought back to operational level or declared non-repairable and redirected to recycling.

Considering the high cost of most LRUs, and possibly their good reliability, they are supplied in (very) small quantities at the operational site of the systems or at a nearby site.This results in system unavailability due to a lack of LRUs. When looking for the reasons for a poor operational availability of a fleet of systems, LRU waiting times take precedence over manpower shortages.

In order to predict the performance of such organizations, two approaches are a priori possible. The first is to build complex models with a large number of variables solved by simulation. But this approach requires significant human resources to build the model and test it; it is then necessary to simulate a large number of events to obtain metrics with small confidence intervals (because some types of events are in the category of rare events). The second approach is to look for a more analytical model such as a queueing network. Unfortunately, the class of product-form queueing networks, for which known algorithms can efficiently handle high-dimensional models, does not allow for accurate model modeling the phenomena of no available LRUs. Of course, Markovian modeling can theoretically describe any discrete event system, but the systems we wish to evaluate here would require dealing with continuous time Markov chains (CTMCs) with state space cardinality in the millions or billions of states. Faced with what we can currently call dead ends, we must consider the search for an approximate solution with the hope of finding one that provides results close to the exact results (on examples of modest dimensions to be computable). Note that many articles exist on inventory management in the context of performance evaluation of maintenance or production systems, and which do not use simulation (*cf.* [1]); but, unless the author is mistaken, they do not take into account the interdependence of unavailable LRU stocks on the operational availability of systems.

This paper, which extends previous results (*cf.* [2] and [3]), is organized as follows. In Section 2, we specify the assumptions and the overall model which consists of a queueing network that does not belong to the class of product-form networks. In Section 3, we introduce a Markovian representation providing the exact stationary distribution of the number of systems blocked by unavailability of spare LRU. The approximate method for dealing with large models is discussed in Section 4. In Section 5, the results provided by the approximate method are used to finally obtain an estimate of the operational availability of the system fleet. Section 6 is devoted to numerical tests to ensure that the proposed approximate method provides results close to those provided by the reference model. Finally, Section 7 constitutes the conclusion of this study.

2 ASSUMPTIONS AND REFERENCE MODEL

We assume that each system consists of N LRU in series. We also assume that M systems are deployed at the operational site. Given the serial structure of a system, we assume here that when a system fails due to the failure of one LRU, the other LRUs cannot fail until the system is back in service. The fleet of systems is considered in steady state and the study focuses on the asymptotic behavior of the features.

R_i denotes the number of LRUs of type i initially allocated as spares at the operational site, $i = 1, 2, ..., N$. Let us introduce the random variable (RV) S_i, $i = 1, 2, ..., N$, defined as the quantity of LRU of type i available on the site at a given time. The possible values of the RV S_i are thus the integers $\{0, 1, ..., R_i\}$. Given the high price of the LRU, the failure of a LRU leads to the ordering of a new LRU from the storage center in charge of the operational site. At a given time, several systems may be blocked due to a lack of LRU of type i. The RV X_i, $i = 1, 2, ..., N$, designates here the number of systems blocked due to a lack of LRU of type i at a given time. Each RV X_i takes its values in the set $\{0, 1, 2, ..., M\}$.

To model the behavior of LRUs stocks, we use the proactive queueing model shown in Figure 1. The presented queue is a $M/M/r < C >$ where C denotes the maximal value of service anticipation (*cf.* [4]) and r is the number of servers. The variable j (resp. i) denotes the number of clients present, (resp. the number of anticipated services available).

In our case, for the LRUs of type i, the number of clients present corresponds to the RV X_i and the number of anticipated services available corresponds to the RV S_i. Note that, by definition, the product $S_i \times X_i$ is always zero. Now consider the RV W_i, $i = 1, 2, ..., N$, defined as the random quantity $W_i = R_i - (S_i - X_i)$. At any time, this quantity corresponds to the number of type i LRUs waiting to be delivered to the operational site.

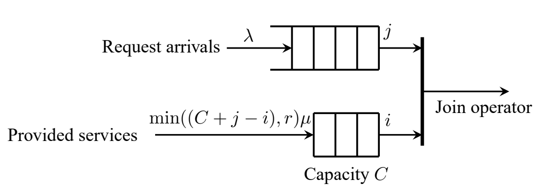

Figure 1: Representation of the proactive queue $M/M/r < C >$.

Our global model is the queueing network represented in Figure 2. The lower sub-network models the N stocks relative to the N types of LRU. This lower sub-network is not a product-form sub-network. But we assume that the upper sub-network is a product-form sub-network. For that we assume that the uptime of the LRUs follow exponential distributions and that all the other stations of the upper sub-network satisfy the necessary conditions. The failure rate for type i LRU is denoted by λ_i, $i = 1, 2, ..., N$.

Let us name NBS the RV "number of systems blocked by lack of available LRUs" ; we have $\text{NBS} = \sum_{i=1}^{N} X_i$. The expectation of NBS is the portion of unavailability attributable to the lack of available LRUs.

Let us put $K_i = M + R_i$, $i = 1, 2, ..., N$; it is easy to see that the possible values of the W_i are the integers $\{0, 1, ..., K_i\}$ and that the knowledge of the couple (S_i, X_i) gives us the value of the RV W_i, and vice versa. Note that if $R_i = 0$, we simply get $W_i = X_i$.

We assume here that the delivery rate of a LRU of type i on the site depends only on the type i of the LRU and on the quantity waiting for delivery (quantity equal to W_i) ; which will allow us to consider a homogeneous Markovian model. The delivery rate of a LRU of type i to the site, knowing that $W_i = k_i$, is denoted $\beta_i(k_i)$, $k_i = 1, 2, ..., K_i$, $i = 1, 2, ..., N$. The values of these rates are here assumed to be known (although we are aware of the required experimental work).

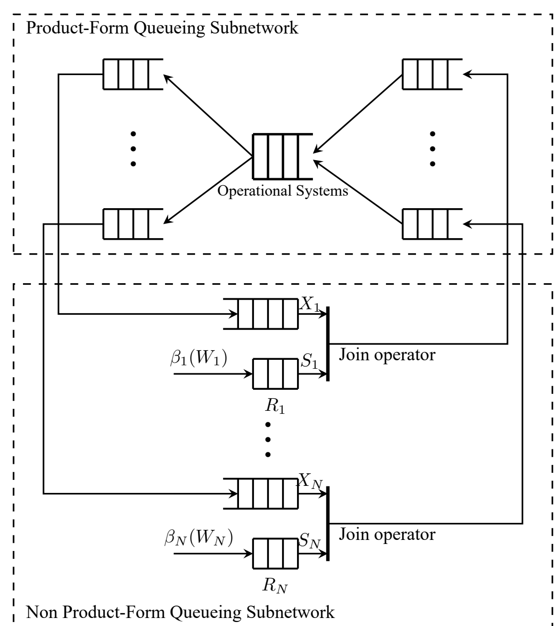

Figure 2: Structure of the global queueing network.

3 EXACT STEADY STATE DISTRIBUTION OF THE RANDOM VARIABLE NBS

The first step is now to aggregate the upper sub-network admitting a product-form into a single station admitting an output rate as a function of the number of systems present in this subnetwork. Let $\nu(n)$ denotes this output rate, $n =$

$0, 1, 2, ..., M$; with of course $\nu(0) = 0$. The determination of these output rates is known for many years (*cf.* [5] and [6]): the expression $\nu(n)$ equals $\gamma_{out} G(n-1)/G(n)$. $G(.)$ is the discrete time convolution function built on the product-form upper sub-network and γ_{out} is, up to an arbitrary constant, the output routing rate obtained thanks to the routing probability matrix $P_r = (r_{ij})$, where r_{ij} is the probability that a customer leaving station i joins station j, and thanks to the vector $\mathbf{x}$, solution of $\mathbf{x} = \mathbf{x} P_r$.

The second step deals with the non product-form sub-network. The continuous time Markov chain (CMTC) whose states are the n-tuples $(W_1, W_2, ..., W_N)$ constitutes our reference model. Let us denote its states by the n-tuples $(k_1, k_2, ..., k_N)$. The state space $\mathbb{E}$ corresponds to the set :

$$\mathbb{E} = \{(k_1, k_2, ..., k_N) |\ 0 \le k_j \le K_j,\ j = 1, ..., N \text{ and } \sum_{j=1}^{N} k_j \le (M + \sum_{j=1}^{N} R_j)\} . \quad (1)$$

To a state $(k_1, k_2, ..., k_N)$ will correspond a vector $(X_1, X_2, ..., X_N)$ whose component values are given by the relation $X_i = \max(0,\ (k_i - R_i))$, $i = 1, 2, ..., N$. In this paper, we will use the simplified notation $(k_i - R_i)^+ \triangleq \max(0,\ (k_i - R_i))$, $i = 1, 2, ..., N$. When the CMTC is in a state $(k_1, k_2, ..., k_N)$, the number of blocked systems, noted here $b(k_1, k_2, ..., k_N)$, is given by the relation :

$$b(k_1, k_2, ..., k_N) = \sum_{j=1}^{N} (k_j - R_j)^+ . \quad (2)$$

Thus, when the system is in a $(k_1, k_2, ..., k_N)$ state of $\mathbb{E}$, the failure rate of LRU of type i is equal to

$$\nu(M - b(k_1, k_2, ..., k_N)) \frac{\lambda_i}{\Lambda} , \text{ where } \Lambda = \sum_{i=1}^{N} \lambda_i . \quad (3)$$

Recall again that, by assumption, the LRU of blocked systems do not continue to fail.

Let us introduce two vector notations: $\mathbf{k}$ denotes the (line) vector $(k_1, k_2, ..., k_N)$ and $\mathbf{e}_i$ denotes a vector whose components are all zero except for the i-th which is equal to unity, the dimension of $\mathbf{e}_i$ being defined by the context. Let us denote $\mathbf{A}$ the infinitesimal generator of the CMTC and $a_{\mathbf{k},\mathbf{k}'}$ the elements of A. The values of the rates $a_{\mathbf{k},\mathbf{k}'}$, for $\mathbf{k}' \neq \mathbf{k}$ are given by the relation :

$$a_{\mathbf{k},\mathbf{k}'} = \begin{cases} \beta_i(k_i) & \text{if } \mathbf{k}' = \mathbf{k} - \mathbf{e}_i \text{ and } k_i > 0, \\ & i = 1, 2, ..., N \\ \nu(M - b(\mathbf{k})) \frac{\lambda_i}{\Lambda} & \text{if } \mathbf{k}' = \mathbf{k} + \mathbf{e}_i, \\ & i = 1, 2, ..., N \\ 0 & \text{else} \end{cases} \quad (4)$$

By letting us put by convention $\beta_i(0) = 0$, we obtain for the diagonal elements $a_{\mathbf{k},\mathbf{k}}$:

$$a_{\mathbf{k},\mathbf{k}} = -\sum_{i=1}^{N} \left(\beta_i(k_i) + \nu(M - b(\mathbf{k})) \frac{\lambda_i}{\Lambda} \right) . \quad (5)$$

The knowledge of the infinitesimal generator $\mathbf{A}$ allows us to obtain the stationary distribution of the states $(k_1, k_2, ..., k_N)$ of $\mathbb{E}$ and thus the stationary distribution of the random variable NBS. This model seems to us to be a relatively accurate representation of the studied system. Unfortunately, the drastic increase of the number of states with the number of types of LRU constitutes the limit of this reference model. For example, when $N = 6$, $R_i = 1$ and $K_i = 40$, $i = 1, 2, ..., N$, the number of states of the CMTC is equal to 16 154 399. It is this limitation that led us to look for the approximate method exposed in the following Section. But this reference resolution will allow to test the accuracy of the approximated method on more modest examples.

4 DETERMINATION OF THE APPROXIMATE METHOD

The proposed model is constructed in a recursive manner. Schematically, in step n, we integrate a fictitious system consisting of n types of LRU in series with a $(n+1)$-th LRU. At the beginning of the step, the behavior of the fictitious system consisting of n types of LRU is characterized by a set of M birth and death processes. At the end of the step, the behavior of the new fictitious system consisting of $(n+1)$ types of LRU is characterized by a new set of M birth and death processes. The $(N-1)$-th and last step, which is simpler, allows to determine an approximate stationary distribution of the random variable NBS.

Slightly particular, the first step constructs the fictitious system comprising only the first two types of LRU. In a first phase, this system is modeled by a CMTC whose states correspond to the possible values of the couples (W_1, W_2), i.e. to the couples (k_1, k_2) of the set $\mathbb{E}_2 = \{(k_1, k_2) |\ 0 \le k_1 \le K_1,\ 0 \le k_2 \le K_2, \text{ et } k_1 + k_2 \le (M + R_1 + R_2)\}$. For a state (k_1, k_2) of this fictitious system, the number of blocked systems, noted $b(k_1, k_2)$, is equal to :

$$b(k_1, k_2) = \sum_{i=1}^{2} (k_i - R_i)^+ . \quad (6)$$

The cardinality of the state space of this CMTC is equal to $|\mathbb{E}_2| = (K_1 + 1)(K_2 + 1) - \frac{M(M+1)}{2}$. The quantity $-\frac{M(M+1)}{2}$ corresponds to the number of forbidden states (k_1, k_2) due to the constraint $k_1 + k_2 \le (M + R_1 + R_2)$.

Let A_2 be the infinitesimal generator of the CMTC. Figure 3 shows the transition rates in the general case.

The Figure 4 gives the structure of the transition graph in the particular case where $M = 4$, $R_1 = 2$, and $R_2 = 1$; the edges in solid line schematize the existence of transitions related to both failures and deliveries of LRU. The vertically hatched states are the states of the CMTC for which no system is blocked due to lack of LRU and the horizontally hatched states are the states of the CMTC for which no further failures can occur because all systems are already non-operational. The dashed edges schematize the transitions related to LRU deliveries only.

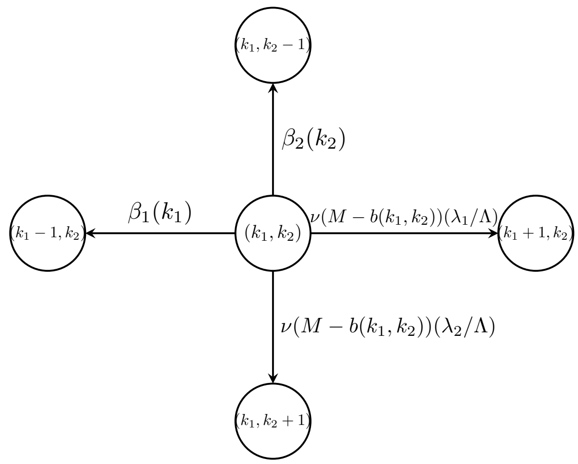

Figure 3: Synthetic representation of the transition rates of the CMTC associated with the couple (k_1, k_2).

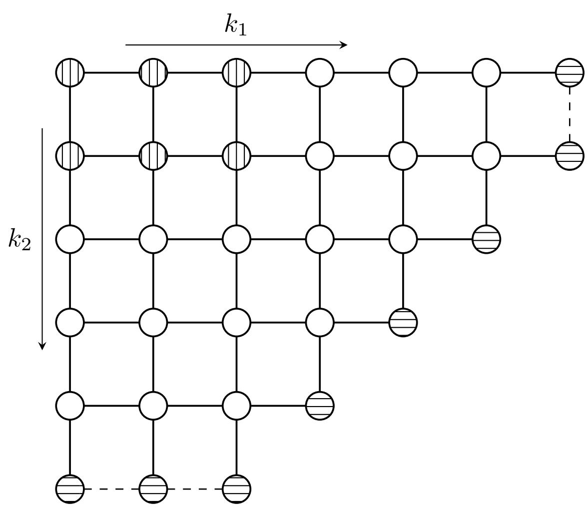

Figure 4: Structure of the transition graph of the CMTC associated to the study of the pairs (W_1, W_2). Special case $M = 4$, $R_1 = 2$, and $R_2 = 1$.

Once the matrix A_2 is known, we determine the vector of asymptotic state probabilities of the CMTC by solving the usual linear system.

Let us denote $p(k_1, k_2)$ the asymptotic probability of the state (k_1, k_2) of the CMTC. These marginal probabilities of X_1 and X_2 are written :

$$p_1(j) = \begin{cases} \sum_{k_1=0}^{R_1} \sum_{k_2=0}^{K_2} p(k_1,\ k_2) & \text{if } j = 0\ , \\ \sum_{k_2=0}^{K_2-j} p((R_1+j),\ k_2) & \text{if } 0 < j \leq M \end{cases} \tag{7}$$

and

$$p_2(j) = \begin{cases} \sum_{k_2=0}^{R_2} \sum_{k_1=0}^{K_1} p(k_1,\ k_2) & \text{if } j = 0\ , \\ \sum_{k_1=0}^{K_1-j} p(k_1,\ (R_2+j)) & \text{if } 0 < j \leq M \end{cases} \tag{8}$$

Thanks to Figure 4, it is easy to understand that for any state (k_1, k_2) such that $k_1 \leq R_1$, X_1 will be null (this explains the expression of $p_1(0)$), while if $k_1 > R_1$, the maximal value of k_2 is $(K2 - j)$.

At this stage, the basic idea consists in constructing from this CMTC associated to the couple (W_1, W_2), a birth and death process (BDP) in order to approximate the behavior of this couple by a unique RV that we will note $\widetilde{W_2}$. Noting $R_{min} = \min(R_1, R_2)$, we notice that we can build a birth and death process by considering the partition $\{\mathbb{E}_{0,0}, \mathbb{E}_{0,1}, ..., \mathbb{E}_{0,R_{min}}, \mathbb{E}_1, ..., \mathbb{E}_M\}$ of the set of states of the CMTC such that

$$\begin{aligned} \mathbb{E}_{0,n} = & \{(k_1,k_2)|\ (k_1,k_2) \in \mathbb{E}, \\ & \text{and } k_1 = R_1 - R_{min} + n, \\ & \text{and } k_2 \leq R_2 - R_{min} + n\} \\ & \cup\{(k_1,k_2)|\ (k_1,k_2) \in \mathbb{E}, \\ & \text{and } k_2 = R_2 - R_{min} + n, \\ & \text{and } k_1 \leq R_1 - R_{min} + n\} \\ & n = 0, 1, 2, ..., R_{min} - 1. \end{aligned} \tag{9}$$

and

$$\begin{aligned} \mathbb{E}_i = & \{(k_1,k_2)|\ (k_1,k_2) \in \mathbb{E}, \\ & \text{and } b(k_1,k_2) = i\} \quad i = 1, 2, ..., M. \end{aligned} \tag{10}$$

On Figure 5 we have specified some examples of classes in order to illustrate the construction of the selected birth and death process.

We can verify that if the CMTC leaves the subset $\mathbb{E}_i$ at time t, it ends up at time t^+ either in the subset $\mathbb{E}_{i+1}$ or in the subset $\mathbb{E}_{i-1}$. The transition rates of the birth and death process are identified with the conditional transition frequencies from one class $\mathbb{E}_i$ to the class $\mathbb{E}_{i-1}$ or to the class $\mathbb{E}_{i+1}$. In the same way, if the CMTC leaves the subset $E_{0,n}$ at time t, it finds itself at time t^+ either in the subset $E_{0,n+1}$ (or E_1 if $n = R_{min}$), or in the subset $E_{0,n-1}$ (if $n > 0$). We have thus defined a birth and death process of cardinality $(M + R_{min} + 1)$.

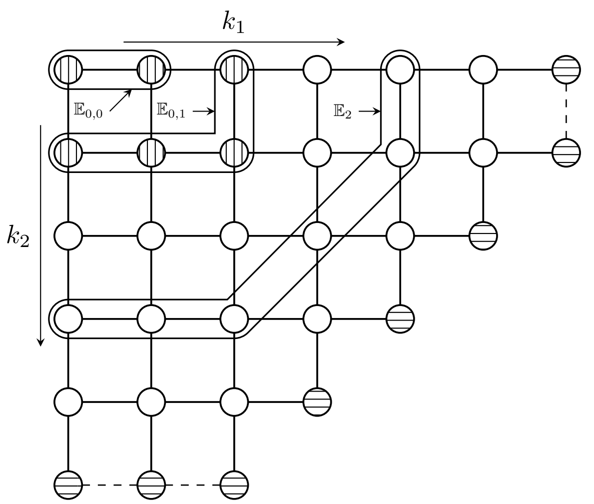

Figure 5: Illustration of the classes of the partition on the structure of the transition graph of the CMTC associated with the study of the pairs (W_1, W_2). Special case $M = 4$, $R_1 = 2$, et $R_2 = 1$.

Since the asymptotic state probabilities $p(k_1, k_2)$ of the CMTC are known, we can compute the transition rates of the birth and death process of cardinality $(M + R_{min} + 1)$ associated with the RV $\widehat{W_2}$. Let us denote $\boldsymbol{\tau}^{(M)}$ (resp. $\boldsymbol{\theta}^{(M)}$) the vector whose $(M + R_{min})$ components correspond to the transition rates associated with failures (resp. deliveries of LRU).

Then we have to repeat $(M - 1)$ times this first phase of step 1 to determine the vectors $\boldsymbol{\tau}^{(m)}$ and $\boldsymbol{\theta}^{(m)}$ associated to a number m of (pseudo) systems formed by the two first types of LRU, $m = 1, 2, .., (M - 1)$. At the end of the first step, M birth and death processes of respective cardinality $(m + R_{min} + 1)$ and their $2m$ vectors $\boldsymbol{\tau}^{(m)}$ and $\boldsymbol{\theta}^{(m)}$, $m = 1, 2, .., M$, have been computed. To simplify the presentation of the second step, we let us put $\widetilde{R_2} = R_{min}$ and $\widetilde{K_2} = R_{min} + M$.

The next step consists in building a CMTC $(\widetilde{W_2}, W_3)$ whose states correspond to the couples $(\widetilde{k_2}, k_3)$ of the set $\mathbb{E} = \{(\widetilde{k_2}, k_3)|\ 0 \leq \widetilde{k_2} \leq \widetilde{K_2},\ 0 \leq k_3 \leq K_3$, and $\widetilde{k_2} + k_3 \leq (M + \widetilde{R_2} + R_3)\}$. The transition graph of this CMTC is similar to the one constructed to study the couple (W_1, W_2) and represented in Figure 4. Note that for a value k_3 of the variable W_3, the possible values of the variable $\widetilde{W_2}$ are the values $\widetilde{k_2} = 0.1, ..., (\widetilde{K_2} - (k_3 - R_3)^+)$.

A subtlety of this CMTC $(\widetilde{W_2}, W_3)$ is the following. For a fixed value k_3 of the variable W_3 such that $k_3 < K_3$, the transition rates associated with the variable $\widetilde{W_2}$ are those of the birth and death process obtained with the value $m(k_3) = \widetilde{K_2} - (k_3 - R_3)^+ - \widetilde{R_2}$, the one whose cardinality of states is equal to $(\widetilde{K_2} + 1 - (k_3 - R_3)^+)$ and whose transition rates are given by the vectors $\boldsymbol{\tau}^{(m(k_3))}$ and $\boldsymbol{\theta}^{(m(k_3))}$. Note that the M birth and death processes determined earlier are needed to study the CMTC $(\widetilde{W_2}, W_3)$. Since $m(k_3)$ is zero when $k_3 = K_3$, there is no birth and death process to provide the transition (death) rates associated with the variable $\widetilde{W_2}$ and necessary if $\widetilde{R_2}$ is positive. In this case, we use the $\widetilde{R_2}$ first components of the vector $\boldsymbol{\theta}^{(1)}$. Figure 6 shows the transition rates in the general case.

The idea behind the approach is to think that the variable $\widetilde{W_2}$, which can be seen describing the behavior of a super-LRU, will behave from the point of view of availability in a way quite close to the first two real LRU.

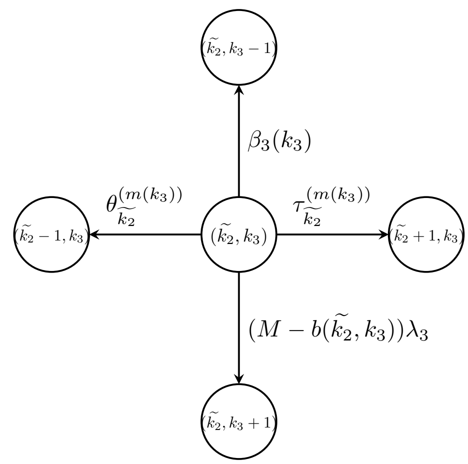

Figure 6: Synthetic representation of the transition rates of the CMTC associated to the couple $(\widetilde{k_2}, k_3)$.

After determining the stationary distribution of the CMTC $(\widetilde{W_2}, W_3)$, we can consider the birth and death process of cardinality $(M + R_{min} + 1)$, where $R_{min} = \min(\widetilde{R_2}, R_3)$, describing the behavior of the $\widehat{W_3}$, and determine the new vectors $\boldsymbol{\tau}^{(M)}$ and $\boldsymbol{\theta}^{(M)}$. As in the previous step, we must study the M CMTC $(\widetilde{W_2}, W_3)$ associated with the values m, $m = 1, 2, .., M$.

Having thus the vectors $\boldsymbol{\tau}^{(m)}$ and $\boldsymbol{\theta}^{(m)}$, $m = 1, 2, ..., M$, we can study the stationary distribution of the new CMTC $(\widetilde{W_3}, W_4)$, with parameters $\widetilde{R_3} = R_{min}$ and $\widetilde{K_3} = \widetilde{R_3} + m$, $m = 1, 2, .., M$ in order to determine the new vectors $\boldsymbol{\tau}^{(m)}$ and $\boldsymbol{\theta}^{(m)}$, $m = 1, 2, .., M$.

In general, we study the stationary distribution of new CMTC $(\widetilde{W_i, W_{i+1}})$, with the parameters $\widetilde{R_i} = \min(\widetilde{R_{i-1}, R_i})$ and $\widetilde{K_i} = \widetilde{R_i} + m$, $m = 1, 2, .., M$ in order to determine the new vectors $\boldsymbol{\tau}^{(m)}$ and $\boldsymbol{\theta}^{(m)}$, $m = 1, 2, .., M$. For the last step, $i = N - 1$, it is sufficient to determine the stationary distribution of the CMTC $(\widetilde{W_{N-1}, W_N})$ associated with $m = M$ to obtain the desired metrics, such as the distribution of the RV NBS and its expectation corresponding to an approximation of the unavailability in asymptotic regime. The skeleton of the general algorithm of the method is represented table 1.

Table 1: General algorithm skeleton.

```
Begin
Initialize the vectors τ^(m) and θ^(m), using the BDP
associated with RV W_1 when the m pseudo-systems
include only the LRU of type 1, m = 1,2,..,M.
n = 1
While n < (N − 1) Do
    For m = 1,2,...,M Do
        Determine the vectors τ^(m) and θ^(m) relative
        to the BDP deducted from CMTC (W̃_n, W_{n+1})
        for which the number of pseudo-systems is
        equal to m.
    EndFor
    n = n + 1
EndWhile
Study the CMTC (W̃_{N−1}, W_N) to deduce the
distribution and the expectation of the NBS.
End
```

This algorithm is much faster and less memory consuming than the algorithm providing the exact solution of the NBS distribution. Moreover, the low relative error of this algorithm (which will be discussed in Section 6) offers the possibility to perform a dynamic allocation of LRUs in order to minimize the NBS expectation under a budget constraint. Concerning the complexity of this new algorithm, it is of the order $O(N.(M + \widetilde{R})^2)$, where $\widetilde{R}$ is the average value of the sequence $R_1, R_2, ..., R_N$.

Let us specify that if $R_i = 0$ for $i = 1, 2, ..., (N-1)$, this method provides the exact solution (identical to that of the reference model). Moreover, some simplifications are possible since in this case the common components of the vectors $\boldsymbol{\tau}^{(m)}$ (resp. $\boldsymbol{\theta}^{(m)}$) and $\boldsymbol{\tau}^{(m')}$, (resp. $\boldsymbol{\theta}^{(m')}$) take identical values.

5 DETERMINING THE OPERATIONAL AVAILABILITY OF THE FLEET OF SYSTEMS

At this stage, we do not yet know the operational availability of the systems because we must also take into account the phases of removing the failed LRUs and reassembling the new ones on the systems. This is the purpose of this last step which consists in approaching the whole sub-network of queues complementary to the station corresponding to the operational systems by a sub-network of queues with a product-form.

To do this, consider the CMTC $(\widetilde{W_{N-1}}, W_N)$ through which we determined the distribution of the NBS. From the stationary distribution of this CMTC, it is very easy to know the probability that a request for LRU of type N will be served immediately; let us note α_N this probability. We can then replace the proactive queue for type N LRU with the product-form subnetwork shown in Figure 7. For $i > 0$, the service rate of this queue, noted $\mu(i)$, is given by $\mu_N(i) = \beta_N(i + R_N)$.

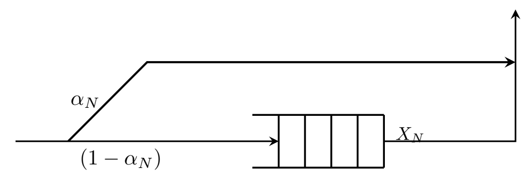

Figure 7: Almost equivalent product-form queue.

To find out the probability that a request for LRU of type j will be served immediately, it is necessary to re-run the algorithm by placing the proactive queue related to the LRU of type j in the last position of the recurrence. We also obtain the values of the service rates of the product-form queue. It is therefore necessary to re-run the algorithm $(N-1)$ times.

Having computed the N probabilities α_j, $j = 1, 2, ...N$, we can then study the almost equivalent product-form queueing network represented in Figure 8. Computing the conditional output rate of the complementary product-form queueing network, we get easily an accurate approximation of the operational availability of the fleet of systems.

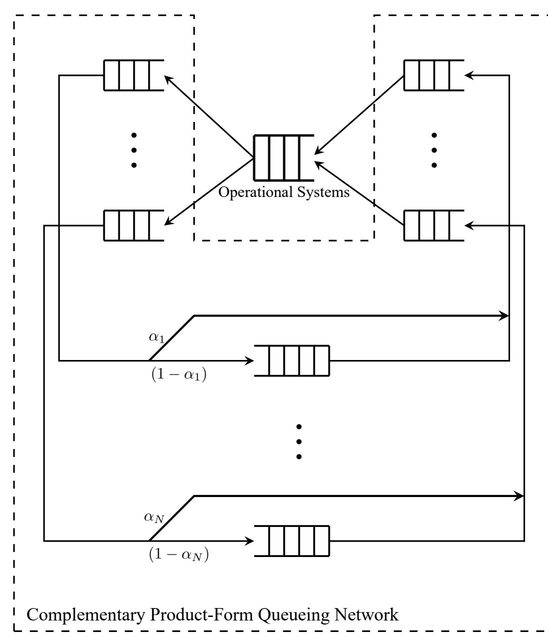

Figure 8: Structure of the final queueing network.

The fact that we need to compute the N probabilities α_j, $j = 1, 2, ...N$ increases the complexity of the proposed method in order to approximate the operational availability of the fleet of systems. The new complexity becomes of the order $O(N^2.(M+\widetilde{R})^2)$. But this complexity is far below the one of the Markovian model whose complexity is of an order greater than $O((M+\widetilde{R})^N)$.

6 NUMERICAL TESTS

We examine the variation of normalized availability ((M-$\mathbb{E}$[NBS])/M) as a function of M when the product $M\lambda_i$ remains constant. To simplify the description of the experimental parameters, the delivery rates $\beta_i(k_i)$ are taken such that $\beta_i(k_i) = k_i\beta$, $i = 1, 2, .., N$.

We consider a version where each system consists of 4 types of LRU in series ($N = 4$). Such a reduced number of LRU types allows to compare the answer obtained with the original method to the exact solution for a reasonable number of M values.

On Figure 9, M varies from 1 to 30 with the product $M\lambda_i$ remaining equal to 0.75, $i = 1, 2, 3, 4$ and the parameter β being equal to 0.6. The availability calculated by this proposed approximate method is represented for the following three situations: i) $R_i = 0, i = 1, 2, 3, 4$, ii) $R_i = 1, i = 1, 2, 3, 4$, iii) $R_i = 2, i = 1, 2, 3, 4$. As expected, the availability increases with the value of R_i.

In the cases $R_i = 1$ and $R_i = 2$, the crosses correspond to the exact solutions calculated for $M \leq 18$ when $R_i = 1$ and for $M \leq 12$ when $R_i = 2$. When the exact values are available, one can notice that the values provided by the proposed method are almost indistinguishable from the exact values. For $M = 10$, the number of states of the reference model is equal to 2,586 and 5,241 respectively when $R_i = 1, i = 1, 2, 3, 4$ and $R_i = 2, i = 1, 2, 3, 4$. Still for $M = 10$, the approximate method gives the result with a relative error of $7.8844\,10^{-5}$ when $R_i = 1, i = 1, 2, 3, 4$ and of $3.9457\,10^{-5}$ when $R_i = 2, i = 1, 2, 3, 4$.

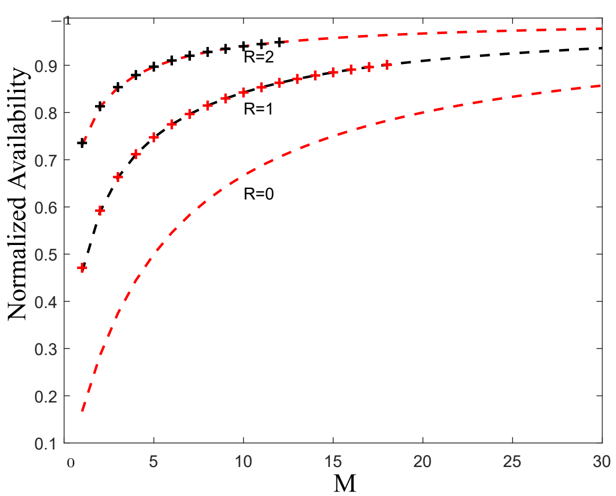

Figure 9: Availability for $R = 0, 1, 2$. Influence of M when the product $M\lambda_i$ remains equal to 0.75. Case $N = 4$ and $\beta = 0.6$.

The second version considered is one where each system consists of 6 types of LRU in series. With this increase in N, we have to reduce the range of the exact results. The product $M\lambda_i$ is here equal to 0.25, $i = 1, 2, 3, 4$. Keeping the other data the same as in the first version, we obtain the results in Figure 10. The exact solutions are computed for $M \leq 8$ when $R_i = 1$ and for $M \leq 5$ when $R_i = 2$. Again, the values provided by the proposed method are almost indistinguishable from the exact values provided.

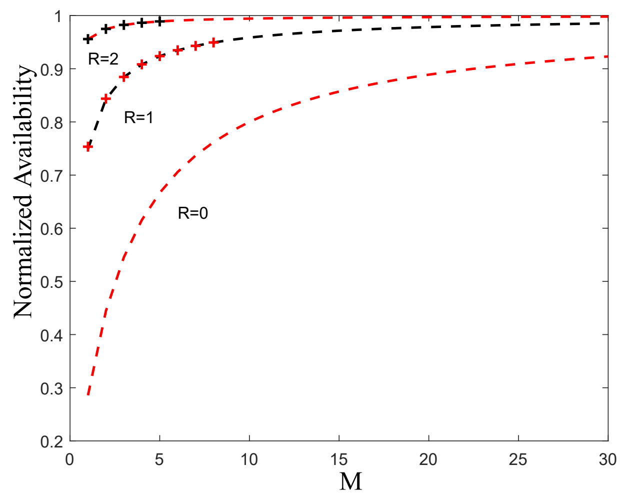

Figure 10: Availability for $R = 0, 1, 2$. Influence of M when the product $M\lambda_i$remains equal to 0.25. Case $N = 6$ and $\beta = 0.6$.

For $M = 5$, the number of states of the reference model is equal respectively to 5,336 and 26,262 when $R_i = 1, i = 1, 2, 3, 4$ and $R_i = 2, i = 1, 2, 3, 4$. For this value of M, the approximate method gives the result with a relative error of $8.4051\,10^{-5}$ when $R_i = 1, i = 1, 2, 3, 4$ and $3.8500\,10^{-6}$ when $R_i = 2, i = 1, 2, 3, 4$. Note that the availability obtained with this version is better than in the previous version whereas here $N = 6$ because the product $M\lambda_i$ is here three times weaker.

Figure 11 illustrates the variation of the relative error of the operational availability as a function of β for $R_i = 1, 2$ and 3, $i = 1, 2, ..., N$, with here $N = 4$ the parameter β varying from 0.01 to 0.7.

Recall that the relative error is zero when $R_i = 0$. We can see that if the precision is acceptable when the value of β is lower than 0.1, it is remarkably weak when β takes values higher than 0.1. Let us add that for $\beta = 0.01$, the operational availability is equal to 0.0703 if $R_i = 1$ and to 0.1142 if $R_i = 3$. For $\beta = 0.1$, the respective values of the operational availability are equal to 0.4779 and 0.7174. While for $\beta = 0.5$, the respective values of the operational availability are equal to 0.8993 and 0.9950. Thus, it is in the useful area of the β parameter that the accuracy of the method is the best. In fact, it is possible that an imprecision on the value of an input parameter creates a greater variation of the operational availability than the one induced by the use of the proposed method. For example, if $\beta = 0.101$ instead of $\beta = 0.1$, the relative variation of the result is $6\,10^{-3}$.

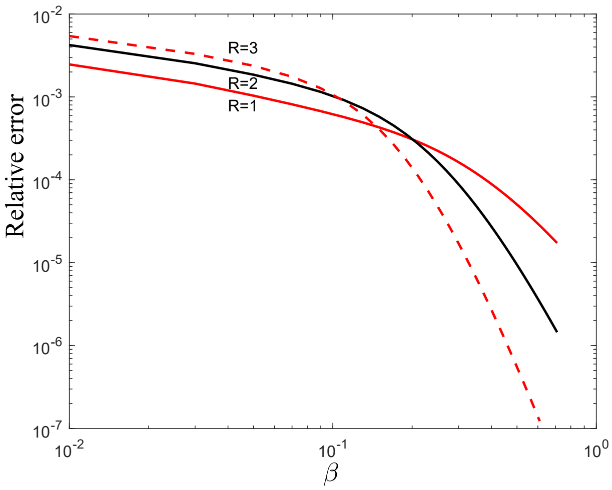

Figure 11: Relative error of the approximate availability as a function of β, for $R = 1, 2, 3$. Case $N = 4$, $M = 8$ and $\lambda_i = 0.05$.

7 CONCLUSION

With this study, we addressed the potential risk of stock shortages of LRU on operational sites of fleet of large systems. To do this, we proposed an original and accurate approximated solution base on non product-form queueing networks giving the expectation of the number of blocked systems due to lake of LRUs. In order to estimate the accuracy of the proposed solution, a Markovian model has been elaborated; this allows us to obtain an evaluation for numerical examples of reasonable size. An additional step allows us to transform with a good accuracy the proactive queues into product-form queues. This finally allows us to determine a new product-form network and to obtain also the operational availability of the systems with a good accuracy. This study shows in addition that for the studied systems, it is the LRU stock-outs that are mainly responsible for low operational availability. Nevertheless, more investigation needs to be dedicated to deeper analyse the effects of large differences between the respective values of the different LRU allocations on the accuracy of the method.

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Numerical Simulation of Conveying Fine Powders in a Screw Conveyor Using the Discrete Element Method

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Due to their high efficiency and spatial utilization, screw conveyors are widely used in pharmacy, agriculture, and industry. Recently, this has made it a popular research subject in the numerical modelling of the transport of bulk solids. Modelling of granular systems at the level of individual particles is mainly possible due to the use of discrete numerical methods. The most common is the use of the Discrete Element Method (DEM), which is still limited from the point of view of simulations on an industrial scale, as increasing the size of the system also increases the cost of simulation. Certain powders with low density, large angles of repose, poor fluidity, and bad flowability can accumulate during transportation, causing inaccurate and non-uniform movement. Additionally, the friction and impact between the particles can cause wear. To address these issues, the present study utilizes the discrete element method to simulate and analyse powder transportation in an inclined screw conveyor using the commercial software ANSYS-ROCKY. Numerous phenomena that arise while transporting and feeding small-sized or irregularly shaped particles, often present in industrial processes, remain insufficiently investigated. This paper aims to analyse the transportation process of adhesive powders in a screw conveyor, with a focus on evaluating the impact of different screw blade speeds on transport. Multiple simulations were conducted, along with the implementation of an additional wear model, to better understand the transport phenomena and wear. An example was used to demonstrate the impact of screw speed on the wear of the transporter due to the interaction between the material and the structure of the conveyor, power consumption, and performance.

Keywords: *discrete element method, conveying equipment, bulk handling, abrasive wear, screw conveyor, coarse graining*

COMPARISON OF IMPROVED ACO ALGORITHMS FOR TOOL PATH OPTIMIZATION IN MULTI-HOLE DRILLING

Luka OLIVARI

Abstract: Optimization of the tool path in the multi-hole drilling process is crucial for reducing the overall cost of production as most of the time is consumed by non-cutting tool movement. Metaheuristics are often used for tool path optimization, with novel and improved algorithms proposed regularly. The observed problem is that proposed algorithms are often compared only to the non-improved versions of metaheuristics or to solutions obtained by CAM software. As expected, improved and novel approaches produce better results than their non-improved counterparts, but it is not known how they compare to the other improved algorithms. Also, the Chebyshev distance matrix is more appropriate for calculating distances in multi-hole drilling. This paper aims to provide data that describes the performance of several improved versions of the ACO algorithm using the Chebyshev distance matrix. By doing so, researchers could easily compare their proposed algorithms to more than just basic ACO to get better feedback about their algorithm performance for tool path optimization.

Keywords: tool path, Ant Colony Optimization, ACO, multi-hole drilling

1 INTRODUCTION

There is a constant effort to optimize different aspects of the CNC machining process like minimizing machining time, airtime, tool path, computational time, tool changing time, and cost, or increasing productivity and surface quality. All of these can be achieved with an improved machine and tool design, parameter, and tool path optimization. [1]

Drilling is an essential operation in CNC machining and multi-hole drilling is a process of drilling a large number of holes in a product. The hole-drilling processes can be divided into single-tool hole drilling (ST) and multi-tool hole drilling (MT) problems. As the name says, in ST only one type of tool is used for drilling, and in MT holes on the workpiece require different tools to be produced. As non-cutting time in the multi-hole drilling process can take up most of the total process time, it is one of the key aspects of optimization in the production industry. That is the main reason why authors often propose new or improved optimization methods for the multi-hole drilling process. Both ST and MT problems are essentially the same from the optimization point of view, because both problems may be represented by Traveling Salesman Problem (TSP). In the ST problem, the cost of the tool moving from hole to hole is represented with a cost matrix, and in the MT problem the cost is the sum of tool change and tool movement which can also be represented with a single cost matrix. [2]

The authors propose three kinds of improvements over the existing optimization algorithms. Completely new algorithms that often draw inspiration or copy some natural process like the mating or hunting habits of animals. Enhanced versions of existing algorithms with improvements to achieve superior performance over the original algorithm. Hybrid algorithms combine multiple algorithms to produce a new algorithm with better performance than its initial components.

Two problems were observed. One problem is that improved or hybrid algorithms for optimization of tool path in multi-hole drilling process are often compared to the basic versions of classical algorithms like Ant Colony Optimization, simple heuristics, or to the tool paths obtained with CAM software, and as expected, achieve better performance. That approach doesn't show how those algorithms compare to the improved versions of existing algorithms. The second problem is that the Euclidian distance matrix doesn't accurately represent travel times or costs in CNC machining [2]. It is because CNC machines use two motors, one for movement along X and the other for the Y axis. If motors are sequentially activated a rectilinear distance matrix would be appropriate. As that is usually not the case, a Chebyshev distance matrix is the most suitable for multi-hole drilling problems because both motors are simultaneously activated, and actual travel time is determined by the longest distance along X or Y axis. As stated in [2] only 19 out of 53 reviewed papers on multi-hole drilling tool path optimization used the Chebyshev distance matrix.

This paper aims to provide comprehensive data on the performance of the improved ACO algorithms applied to the benchmark TSP instances using the Chebyshev distance matrix which can be calculated using expression (1). The goal of this paper is to enable researchers quickly and easy comparison of proposed algorithms for tool path optimization in multi-hole drilling to more than just the basic Ant System.

$$d_{ij} = \max\left(\left|x_1 - x_2\right|, \left|y_1 - y_2\right|\right) \tag{1}$$

Data will also be provided for the performance of the improved ACO algorithms on the same benchmark problems using the Euclidean distance matrix. There are two reasons for that. First, the optimal or best-known solutions for these benchmark problems are known for the Euclidean distances between nodes, but not for the Chebyshev distances. That makes it hard to calculate the relative maximum deviation from the optimum for the optimization algorithm. It is reasonable to expect similar values for the relative maximum deviation for Euclidean and Chebyshev distances, so by providing data for one case, the other can be approximated. The second reason is that a lot of authors use the Euclidean distance matrix in their algorithms, and we want to provide data for easy comparison in that case too.

The following paragraph contains a short literature survey to showcase a comparison of new and improved algorithms to basic heuristics, meta-heuristic, or CAM software results. In [3] authors propose a novel Bat Algorithm (BA) that draws inspiration from bat hunting behavior. The BA algorithm was compared to Genetic Algorithm, Particle Swarm Optimization, Ant Colony Optimization, and Artificial Bee Colony algorithms. In [4] authors apply Genetic Algorithm with a modified cross-over method to a workpiece with 28 holes to optimize the tool path for energy-efficient machining. Results were compared with the tool path generated by Autodesk Inventor. In [5] authors use Artificial Neural Networks and a hierarchical refinement process for fast tool path optimization. Results were compared to those obtained with the greedy algorithm followed by 2-opt. In [6] authors use a simulated annealing algorithm combined with an adaptive large neighborhood search to optimize the laser cutting path. The problem is represented with generalized TSP and results were compared to commercial CAM software and similar scientific papers.

After an introduction, in chapter 2 Ant System, its improvements, and the differences between them are described, test results and discussion are presented in chapter 3, and concluding remarks in chapter 4.

2. ANT COLONY OPTIMIZATION

Ant Colony Optimization (ACO) is a metaheuristic optimization framework that encompasses a variety of algorithms inspired by the stigmergy of the ant colonies in search of food. Ants in nature use the stigmergy mechanism, a form of indirect interaction, by modifying their environment with pheromone trails. Ants, unaware of each other, lay and "read" the pheromone trail to obtain information. An ant that has found the food source deposits a pheromone trail which increases the probability that other ants will follow the same path to the food source. The more ants use that path, and lay their pheromone, the chance for other ants to follow that path increases.

Artificial ants in ACO algorithms have a similar approach which can be used to solve a wide range of optimization problems, especially problems that involve finding the shortest path in a graph, such as the Traveling Salesman Problem (TSP) and Vehicle Routing Problem (VRP). Ant System (AS) was the first algorithm in the ACO metaheuristic optimization framework. Although AS didn't perform as well as other algorithms for solving TSP at that time, its main value is that it inspired many other ACO algorithms with significantly improved performance. Some of those improved algorithms are Elitist AS, Ranked AS, and MAX-MIN AS. The main difference between an original AS and its "classical" improvements is in the pheromone update mechanism. [7]

Pheromone is updated after all ants in the current iteration have completed their tours. The first step of pheromone update is pheromone evaporation, i.e. lowering pheromone levels by a constant percentage, after that, new pheromone levels are added. Pheromone evaporation is regulated with parameter ρ to stop pheromones from rising infinitely and to deter ants from exploring bad tours and edges which accumulated pheromones by chance. Parameter ρ can be set in a range from 0 to 1, and it represents the percentage of how much of accumulated pheromone evaporates between iterations.

After evaporation, ants deposit pheromones on the edges used for constructing their tours. The amount of pheromone Δτk deposited by ant k depends on the tour quality. The shorter the tour the more pheromone is deposited. Edges used by many ants with short tours receive a lot of pheromones so there is a higher probability for that edges to be chosen in the next iterations. Pheromone evaporation and deposition are modeled according to the expression (2).

$$\tau_{ij}^{k} = \left(1-\rho\right)\tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \tag{2}$$

Elitist Ant System (EAS) increases amounts of pheromone deposition on the edges that make the best-so-far solution Tbs created since the beginning of the process. This tour can be viewed as an additional elite ant that deposits a pheromone in each iteration. The length of Tbs is denoted by the Cbs. The amount of additional pheromone added to the best-so-far solution is calculated by e/Cbs, where e is the weight given to the best-so-far solution.

Ranked-based Ant System (RAS or ASrank) is an extension of the Elitist Ant System in which amounts of deposited pheromone depends on the ant's rank r, i.e. the quality of the solution obtained by each ant. As in EAS the ant with the best-so-far solution deposits the most pheromones in each iteration, the second best-so-far ant deposits fewer pheromones, etc. The number of ants that deposit pheromone is denoted with w and the amount of pheromone deposited by the best-so-far is calculated by w·1/ Cbs and by the rest of the ranked ants is (w-r) ·1/ Cr, where Cr is the length of the solution by rth ant.

High-quality solutions are obtained by combining ACO algorithms with Local Search because they complement each other. In fact, the definition of the ACO framework allows using local search. There are lots of ways to combine Local Search with ACO algorithms, a general rule is the better solution comes at the price of longer computation time. We used the 2-opt algorithm, as one of the basic Local Search algorithms. 2-opt switches two pairs of edges in all possible combinations for the given tour to eliminate any cross-overs of edges. For in-depth descriptions of the Ant System, its extensions and possible combinations with the Local Search reader are directed to [7].

3 EXPERIMENT AND DISCUSSION

As both ST and MT problems can be represented with Traveling Salesman Problem, Ant System and its improved versions were applied to TSP benchmark problems eil51 and eil101 found in TSPLIB [8]. The best-known solution for eil51 is 426, and for eil101 is 629. The parameters used for each algorithm are shown in table 1. Used parameters are recommended parameters for general good performance from [7], except for the number of ants. Preliminary testing showed a significant increase in computation time at the price of slightly worse solutions. Using 101 ants for the eil101 Ant System produced an average solution of 696,5 in 85 seconds, while Rank-based AS produced an average solution of 651,5 in 80 seconds. Parameter β has recommended value in the range 2 – 5, we used the upper limit $\beta = 5$, as it produced better results in preliminary testing. Initial pheromone levels τ_0 are calculated according to the equation in the table, where C^{nn} is the length of tour obtained with the Nearest Neighbor algorithm.

Table 1 ACO parameters

	α	β	ρ	m	τ_0	
AS	1	5	0.5	25	m/C^{nn}	-
EAS	1	5	0.5	25	$(e+m)/\rho C^{nn}$	$e = m$
RAS	1	5	0.1	25	$0.5r(r-1)/\rho C^{nn}$	$w = 6$

As mentioned before, there are lots of ways to combine ACO with Local Search algorithms. In our case, we used the least computationally intensive Local Search algorithm, 2-opt, and apply it after all ACO iterations to improve only the final solution. No special speed-up techniques were used for ACO algorithms nor 2-opt which means that faster performance is possible.

Testing was performed on Windows 10 64-bit operating system using MATLAB R2021a. The computer configuration was Intel(R) Core(TM) i5-10210U CPU 2.10 GHz, installed RAM 8 GB. Code used can be found on the GitHub repository [9]. The stopping criteria were 300 iterations, and every algorithm was run 20 times to average out results.

Algorithm performance was analyzed using the following metrics: 1) best solution overall, 2) average solution quality, 3) relative standard deviation, 4) relative maximum deviation, and 5) average execution time.

The best solution overall is the best solution produced by the given algorithm in all runs. Average solution quality is calculated by the mean of the best solutions produced in all 20 runs by a single algorithm. Relative standard deviation is calculated by dividing the standard deviation from the optimal solution and given in form of a percentage. It shows how precisely the algorithm produces solutions close to the optimum. The maximum deviation is calculated by dividing the worst final solution in all runs by the optimal solution and given in form of a percentage. It shows the worst expected performance of the algorithm with given parameters. It is used only for the Euclidean distance matrix because the optimal solution using the Chebyshev distance matrix isn't known. Average execution time is wall-clock time for a single run of the algorithm i.e., time to compute all iterations until stopping criteria are met, including the Local Search. In table 2. and table 3. test results are presented. The numbers in the first column correspond to the numbers before the metrics in the text above.

Table 2 Test results, Chebyshev distance matrix

eil51	AS	EAS	RAS	AS + 2-opt	EAS + 2-opt	RAS + 2-opt
1)	378	**377**	**377**	**377**	**377**	**377**
2)	388	382,2	379,3	381,5	379	**378,2**
3)	0,8%	0,86%	**0,54%**	1,17%	0,61%	0,6%
4)	-	-	-	-	-	-
5)	8,1 s	7,9 s	7,9 s	8,1 s	**7,8 s**	7,9 s
eil101	AS	EAS	RAS	AS + 2-opt	EAS + 2-opt	RAS + 2-opt
1)	595	569	570	576	569	**565**
2)	623	591,3	587,8	590	579,2	**576**
3)	2,32%	3,04%	2,86%	2,16%	1,6%	**1,39%**
4)	-	-	-	-	-	-
5)	20,8 s	21,1 s	**19,4 s**	21,7 s	21,1 s	19,5 s

Table 3 Test results, Euclidean distance matrix

eil51	AS	EAS	RAS	AS + 2-opt	EAS + 2-opt	RAS + 2-opt
1)	449,6	429,5	430,4	431,3	**429**	429,1
2)	457,9	437,4	435,4	439,2	433,1	**432,8**
3)	1,02%	1,28%	0,87%	1,15%	**0,71%**	0,72%
4)	8,77%	5,35%	4,67%	4,92%	**4,16%**	**4,16%**
5)	8,1	8,1	**7,6 s**	8,3 s	8,1 s	7,7 s
eil101	AS	EAS	RAS	AS + 2-opt	EAS + 2-opt	RAS + 2-opt
1)	691,3	642,5	649	657,4	643,1	**642**
2)	705,7	669,1	661,3	671	653,2	**649,5**
3)	1,25%	2,31%	1,59%	1,3%	1,14%	**1,13%**
4)	14,74%	11,95%	9,05%	9,13%	5,93%	**5,79%**
5)	20,5 s	20,5 s	**19 s**	21,2 s	21,3 s	19,7 s

As expected, Rank-based AS produced slightly better average results than Elitist AS, which in turn produced better results than the basic Ant System. Applying 2-opt improved all average solutions in all three algorithms. The same best overall solution for eil51 and Chebyshev distance matrix was achieved by all algorithms except AS, while the best average solution was produced by RAS and 2-Opt. The best overall solution for eil101 was produced with RAS combined with 2-opt, while the best overall solution for eil51 and Chebyshev distance matrix RAS and 2-opt. The worst maximum deviation for the Euclidean distance matrix was produced by

Ant System, and it can be concluded that the worst maximum deviation for the Chebyshev distance matrix could also be expected from Ant System. Rank-based AS, without 2-opt, had the lowest computational time. The reason for that is the shorter pheromone update calculation, because in RAS only the top *w* number of ants deposit pheromones, while in other algorithms all ants deposit pheromones.

Coupling ACO algorithms with better Local Search algorithms like 3-Opt or Lin-Kernighan Heuristic could produce much better results at the price of longer computation time. Longer computation could be somewhat countered with the use of speedup techniques for ACO and Local Search algorithms.

4. CONCLUSIONS

Data on the performance of the Ant System and improved ACO algorithms, Elitist Ant System, and Rank-based Ant system using the Chebyshev distance matrix for TSP is provided. Data can be used for comparison of newly proposed or improved algorithms for tool path optimization in multi-hole drilling. Of course, used algorithms could achieve much better performance if parameters were fine-tuned for specific problems, but as the main purpose of this data is to enable quick and easy comparison of newly proposed algorithms to the more than just Ant System, it is more appropriate to use recommended parameters for generally good performance.

For future research, algorithms could be applied to other benchmark and industrial problems, especially larger ones. More improved ACO algorithms could be included for easy comparison, as well as improved versions of other heuristics and metaheuristics. Also, a framework for comparison of meta-heuristics would be very useful as well as benchmark problems specific to multi-hole drilling.

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PROBING THE ROLE OF PYTHON AND JUPYTERLAB IN TEACHING OPERATIONS MANAGEMENT

U. Aytun OZTURK

Abstract: This paper describes the integration of the use of Python programming language into an operations management course to aid students in solving managerial problems. Throughout the course, short lectures and interactive problem-solving sessions were relied upon to reinforce the concepts covered while applying Gagne's nine events of instruction. Python and JupyterLab were used for various tasks, including data analysis, visualization, and optimization. The students' achievement of learning outcomes was measured using multiple assessment tools. Future work may include integrating AI-powered tools and distributed control systems like GitHub to enhance students' learning experience.

Keywords: Higher education, JupyterLab, operations management, Python, teaching.

1 INTRODUCTION

Multiple graduate-level courses in logistics and operations research (OR) are taught worldwide by integrating Python [1]–[3]. There are also undergraduate courses in analytics, data science, economics, industrial engineering, information systems (IS), or systems engineering for which instructors pursue similar approaches [4]–[9]. However, the literature has no evidence of Python and JupyterLab's integration in teaching operations management (OM) at the undergraduate level, and textbooks that utilize this approach are lacking.

Python is an increasingly popular choice for coding, augmented by diverse open-source libraries such as **NumPy, Pandas, and Matplotlib**, capable of data analysis and implementing machine learning algorithms, and is regarded as the industry standard general-level programming language. It is reasonably easy to learn, supported by well-developed online tutorials. Multiple platforms are available for implementing Python, including JupyterLab. JupyterLab is an online interactive development environment for notebooks, which can be used to code and collaborate, enabling the user to receive immediate feedback. This platform's existing online tutorials allow users to combine comments, code, and visualizations, simplifying students' mastery of Python. Students have the potential to use this powerful yet flexible duo to solve OM problems while generating visualizations that can support their critical thinking and presentation skills. The analytics, economics, operations research, and statistics disciplines have already embraced these game-changing approaches that OM educators can benefit from. Adoption of languages such as Python is expected only to accelerate, incentivized by the market demands of analytics-literate graduates [10]–[12], as evident from the university-wide initiatives at the University of Michigan and the University of California [13], [14].

This paper focuses on a first attempt to integrate the use of Python and JupyterLab in an elective introductory operations management course for third and fourth-year liberal arts students who are non-native speakers of English at a private university in Japan. The elective OM course was revised as an intermediary step to design a new elective course focusing on prescriptive analytics methods for operations management. The typical students in the course pursue a bachelor's degree in international liberal arts. Within this degree program, students can pursue one of the three specializations offered in history and culture, international relations and politics, or economics and business administration. Before enrolling in the OM course, the students generally complete introductory-level statistics and business courses and an additional elective in statistics, mathematics, or programming. A few students also take an introductory management science course prior to the OM course. In addition, the course attracts students pursuing bachelor's degrees in business and economics. The students' diverse backgrounds result in heterogeneity in the skills brought to the classroom, while the common curriculum ensures student familiarity with the foundations of business and statistics. However, since programming is not an enforceable prerequisite, the challenge of learning the basics of Python while implementing code to solve OM problems exists. Therefore, Python is used as a tool to solve OM problems with a focus on practical applications rather than technical coding skills. In this way, students can be provided the code for problem-solving and are guided in revising it as needed for different instances. Since it is not likely that many of these students will pursue OM or IS career paths, this approach is sufficient for them to understand the fundamentals and integrate aspects of the knowledge they gain into their current coursework or future careers as they communicate with employees specialized in OM or IS. Furthermore, some students pursue seminars in Data Science, Economics, and Business concurrent with the OM course, and build on the knowledge and skills gained in this course in writing their junior papers, a graduation requirement for the liberal arts degree they pursue.

The author's intention in this paper is to share the approach to teaching introductory OM for liberal arts students by utilizing modern programming tools [5], [15], [16]. The topic covered in this paper fills a gap in the literature which primarily focuses on teaching logistics using Python for graduate students or computer science (CS) and OR for undergraduate students [16], [17]. The rest of the paper is structured as follows. First, we describe the design process and the rationale for choosing Python and JupyterLab. Then, we provide the course structure, teaching, and assessment experience, including how JupyterLab is used with sample Python codes for the two of the topics covered in the course. Next, we state observations based on the student feedback to demonstrate evidence in support of the approach utilized. Finally, we summarize the path for further revisions, considering the evolving Artificial Intelligence (AI) support students can obtain via platforms powered by large language models such as Generative Pre-trained Transformer (GPT) in their learning journey.

2 BACKGROUND

In a traditional introductory OM course, Excel and other software are used in problem-solving [18]. Although necessary for some degree programs, these approaches can be augmented or replaced by new approaches. For example, for liberal arts students, using Python and JupyterLab is a suitable replacement for the rote calculation or spreadsheet approaches used in introductory OM textbooks. Three anticipated benefits may arise from this replacement: increased familiarity with programming for the students, instructor's ability to focus on real-life cases involving large datasets for the course, and alignment of the student skillsets with the job market's needs. As a result, students have the opportunity to benefit from coding in completing, customizing, or automating predictive and prescriptive tasks encountered in problem-solving within an OM course. Using more powerful tools like Python also enables the instructors to use larger datasets whose handling and visualization would be more challenging with manual or Excel-based methods. Furthermore, from a macro standpoint, embedding the application of programming into the course would align it with the initiative undertaken by the Ministry of Education in Japan that promotes the integration of data science and AI into curriculums.

There are numerous approaches instructors can adopt while designing a course that utilizes programming [19], [20]. For instance, students may be required to take a programming course as a prerequisite, or a review may be integrated as a module within the course. Alternatively, the focus can be on foundational programming skills that prioritize familiarity [21] by enabling students to learn from code snippets in solving OM problems and revise them as necessary, which is the approach pursued in this course. The design phase also involves the selection of the programming language to ensure that the skills gained will be long-lasting. The liberal arts students who enroll in the course are familiar with either R or Python due to the use of these languages in at least one of the courses that students may take before their junior year. Both languages are open-source options and attractive due to cost considerations. However, the latter is preferable since it is consistently the top general-purpose programming language in rankings published by TIOBE, IEEE, GitHub, and Stack Overflow [22]–[25]. It is also convenient that the Python packages necessary for this course can easily be installed using the ***pip*** package manager.

The subsequent design decision is the selection of the platform for using Python. For this purpose, we adopted the approach taken by the data science program at the University of California in Berkeley and chose JupyterLab. This open-source platform builds on the popular Jupyter interface known formerly known as IPython Notebook. However, JupyterLab is more versatile, with the capability of displaying multiple sub-tabs within the same browser tab and better display options for comma-separated value (CSV) files. It also comes with other improvements, such as split views and simultaneous views for code and text explaining it, known as markdown, which can contain hypertext markup language (HTML) or La-Tex. Furthermore, the display is achieved via a Java-script Object Notation (JSON) document that enables the input of Python code in cells that the user can execute to run the code in chunks or even line by line without the need to complete the entire code for a task at hand [26].

3 TEACHING EXPERIENCE

The OM course structure before this latest revision is the culmination of 20 years of teaching experiences of the course instructor in the US, China, and Japan, at the undergraduate and graduate levels. Interactions with students from different backgrounds and diverse language proficiency levels contributed to the methods utilized in the course, including hands-on problem-solving sessions following the First Principles of Instruction [27] and flipped classroom approaches. This latest innovation fits well with the existing interactive learning experiences, lauded by the students and catering to varying learning styles for the course.

The course learning outcomes relevant to the paper are highlighted in Tab. 1, and the course content is noted in Tab. 2. The use of Python and JupyterLab is directly relevant to objectives 1b, 1c, and 2c.

Table 1 Learning outcomes and objectives

Course learning outcomes	Corresponding learning objectives (*Structure of Observed Learning Outcome* taxonomy level)
1. Develop skills in quantitative research methodologies.	a. Identify different types of forecasting methods for OM. (multi-structural) b. Explain the steps involved in developing a forecast. (relational) c. Draw appropriate conclusions by applying forecasting techniques to analyze and interpret data. (extended abstract)
2. Develop analytical solutions for a set of OM problems.	a. Recognize and define the elements of an OM problem. (multi-structural) b. Analyze and compare different methods for solving an OM problem. (relational) c. Create a solution for an OM problem by applying the appropriate model and providing its justification. (extended abstract)

Table 2 Course content

Topics	Sessions utilizing Python
Introduction to OM	No
Operations Strategy	No
Product and Service Design	No
Forecasting and Demand Planning	Yes
Capacity Planning	Yes
Location Decisions	Yes
Process Selection and Facility Layout	Yes
Aggregate Planning	Yes
Inventory Management	Yes
MRP and ERP	Yes
Scheduling	Yes

At the beginning of the course, students were reminded that Python would be utilized to demonstrate how the methods covered in the textbook are applied, reinforcing the message disseminated via the syllabus. Students who had not completed a programming course were encouraged to enroll in a course concurrently with the OM course or self-study using online resources, including platforms such as edX. It was also emphasized that programming skills are not required and that an alternative to Python is to solve problems manually or to use Excel, both of which are covered at length in the textbook adopted. Since the initial part of the course did not involve Python, students had the opportunity to familiarize themselves with the language independently or seek help during office hours in the first six weeks of the semester.

The following steps were utilized for each topic that calls for the use of Python, as noted in Tab. 2. Applying Gagne's nine events of instruction [28], sessions commenced with coverage of recent news articles or video clips related to the topic to grab the students' attention (event 1). This was followed by a review of the course schedule, reminding the students of topics covered in the previous class and the topic and objective for the current session (events 2 and 3) relating it to event 1. Next, depending on the content and student preference, multiple approaches were used, including a long lecture followed by a problem-solving session for a significant question or short lectures, each followed by a problem-solving session. Most of these problem-solving sessions typically integrated Python. For these problem-solving sessions, a well-defined statement was first provided for the student (event 4). Then they were provided the Python code snippet and a verbal and written explanation of what it could be used for so they could replicate the process themselves using their workstations (events 5 and 6). This activity was followed by a brief discussion or explanation of how to interpret the results obtained (event 7). Next, the performance was assessed with a follow-up question requiring them to use the code differently, using different input values or involving slight code variations (event 8). Finally, after covering alternative solution methods, students were asked to generate solutions by choosing from multiple possible ways presented (event 9).

Potential examples of two simple code snippets (JupyterLab notebooks) for sessions integrating Python are provided in Fig. 1 through 4. These notebooks can be saved as standalone documents that can be compiled and converted to other forms for presentation. Fig. 1 and 2 illustrate the use of Python for plotting the weekly demand data, followed by forecasting via a rolling horizon of three periods via simple moving averages for a sample problem. The resulting table displays the observed values along with forecasted values. As can be seen, markdown is separate from the code but can also be integrated within the code if need be. Fig. 3 demonstrates how Python can be used to compare the construction costs of a plant at four different locations. Fig. 4 shows the resulting plot. The markup cells in JupyterLab display the comments for different parts of the code so students can follow along and modify them as necessary for the sample problem or other problems they tackle. The course also uses Python to accomplish other tasks that require the use of factor rating, the center of gravity and load-distance calculations, ABC analysis, solving transportation problems, as well as relating to the topics of facility layout, scheduling, aggregate planning, forecasting via weighted moving averages, exponential smoothing, and simple and multiple linear regression.

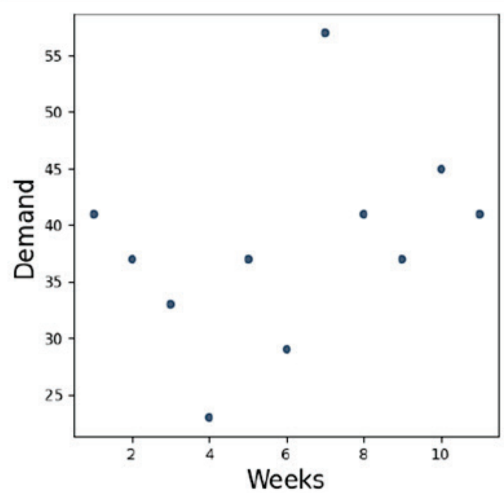
```
In [1]: from datascience import Table
        import numpy as np
        import matplotlib.pyplot as plt
        import pandas as pd
        %matplotlib inline
```

Read data from CSV file PLEASE ENTER THE FILE NAME

```
In [2]: original = Table.read_table('Organicfood.csv')
```

Extract the 'Weeks' and 'Demand' columns and plot the scatter plot

```
In [3]: demand = original.select('Weeks', 'Demand')
        demand.scatter('Weeks')
```



Create a pandas dataframe and calculate the moving average of demand

```
In [4]: df = demand.to_df()
        n = 3 #PLEASE ENTER THE ROLLING HORIZON HERE
        df['MA'] = df['Demand'].rolling(window=n).mean()
```

Concatenate NaN values with the calculated moving average array

```
In [5]: MA = np.concatenate((np.array([np.nan]*(n-1)), df['MA'][n-1:].to_numpy()))
```

Figure 1. Calculating moving averages

Add the moving average column to the demand table

```
In [6]: F = demand.with_columns('MA', MA)
```

Display the table

```
In [7]: F.show()
```

Weeks	Demand	MA
1	41	nan
2	37	nan
3	33	37
4	23	31
5	37	31
6	29	29.6667
7	57	41
8	41	42.3333
9	37	45
10	45	41
11	41	41

Figure 2. Calculation of moving averages

Import matplotlib and numpy libraries

```
In [3]: import matplotlib.pyplot as plt
        import numpy as np
```

Generate data by first creating an array of 20000 values representing quantity

```
In [4]: quantity = np.array(range(20000))
```

Calculate the cost for each location based on quantity

```
In [5]: cost_location_a = 450000 + 15 * quantity
        cost_location_b = 270000 + 35 * quantity
        cost_location_c = 200000 + 50 * quantity
        cost_location_d = 350000 + 30 * quantity
```

Plot the cost for each location against quantity
Add title, x-axis and y-axis labels
Add a grid to the plot
Add a legend to the plot
Format the y-axis ticks to have comma separators remove offsets
Set the y-axis limits to start from 190,000 and step every 200,000 units
Display the plot

```
In [6]: plt.plot(quantity, cost_location_a, linestyle='-', label='Location A')
        plt.plot(quantity, cost_location_b, linestyle='--', label='Location B')
        plt.plot(quantity, cost_location_c, linestyle='-.', label='Location C')
        plt.plot(quantity, cost_location_d, linestyle=':', label='Location D');
        plt.title('Cost-Profit-Volume Analysis', fontsize=16)
        plt.xlabel('Quantity (units)', fontsize=14)
        plt.ylabel('Total Cost (USD)', fontsize=14);
        plt.grid(alpha=4, linestyle='--');
        plt.legend(fontsize=12);
        plt.ticklabel_format(style='plain', axis='y', useOffset=False)
        plt.gca().get_yaxis().set_major_formatter(
            plt.FuncFormatter(lambda x, p: format(int(x), ',')))
        plt.ylim(190000, max(cost_location_d)+250000);
        plt.show()
```

Figure 3. Python code for plotting cost figures

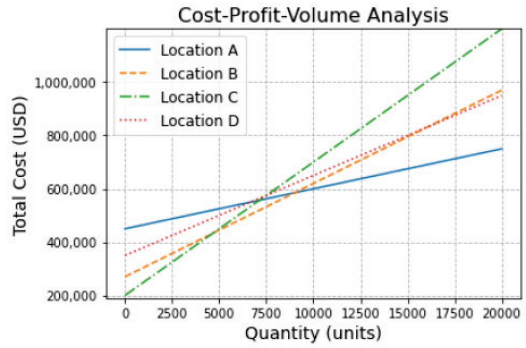


Figure 4. Total cost plot

In the course, Python was used while focusing on visualization, data analysis, and optimizing processes. Although the data used in this iteration was limited to textbook data, cases with actual data will be utilized in future repetitions. The approach adopted moves students beyond creating spreadsheets and manual calculations using formulas. Instead, it provides them with tools to analyze data and test different scenarios for what-if analysis to obtain answers to OM problems without getting bogged down on details of the formulae. Students' achievement of the learning outcomes was measured via multiple assessment tools, including individual assignments such as exams and various quizzes (both scheduled and unannounced), as well as an end-of-semester team-based project that culminated in a paper and presentation. The topics for the project were derived from the textbook adopted. Students were also assigned ungraded homework problems to work on independently or in teams. The challenges students faced in solving these problems were addressed as well.

4 OBSERVATIONS

Overall, the teaching experience for this intermediary step in integrating Python into the OM curriculum was illuminating in multiple ways. First, although most students relied on Python instead of Excel or manual calculation, there were still those who chose the latter two approaches. Even the students who used Python reverted to Excel for familiar tasks, such as using the Data Analysis add-in in Excel to calculate simple moving averages. However, they embraced Python for more complicated tasks, such as ABC analysis, where Excel fell behind.

Since this is the first time the course was taught by integrating Python, the quantitative evidence derived from the course evaluations is not statistically significant. However, for all the questions students answered for the course, the average response was greater than 4 out of 5. Students commented on the value of using Python in solving OM problems, indicating a craving for more of its use. However, some students stated that grasping all the code details was challenging. This challenge was expected at the outset since not all students took a programming course before registering for OM, resulting in a steeper learning curve.

5 FUTURE WORK

Naturally, continuous improvement of any course is vital to keeping it relevant. This can be achieved via a multi-prong approach, including real-time polls during selective lectures, mid-semester course surveys, reflection upon the end-of-semester surveys, personal interactions with students, and benchmarking. As a result of the feedback received, the following revisions may be necessary moving forward.

First, given the recent developments in AI, AI-powered tools can provide students with personalized learning experiences, answer their questions, and guide them through challenging concepts. For instance, OpenAI's GPT, a language model trained to assist users in generating human-like responses to text-based queries, can provide students with real-time support in solving OM problems using Python and JupyterLab during in-class sessions and outside the classroom.

Second, GitHub, a platform that uses a distributed control system for software development, can be adopted for course projects enabling students to collaborate in real-time, building on the private course repository that can be created on GitHub.

Third is a better use of other cloud services. This course required students to use the Anaconda distribution of Python and JupyterLab. Moving all the coding tasks to Anaconda Cloud, a free platform that enables users to access JupyterLab online, may be possible. This move would eliminate the time needed to install JupyterLab and Python and the coaching necessary for each student for the respective operating system they use. However, there are limitations as to what can be completed using this cloud service. For instance, the free option is limited in the data that can be uploaded and the number of people with which you can share your data with. There are also other limitations, such as limited storage and customization, as well as dependence that can result in solely relying on Anaconda.

Finally, based on the student feedback, it is necessary to dedicate additional time to Python basics to ensure students feel more comfortable using Python as an alternative and understand that it is more powerful than Excel, which they are more fluent with. Furthermore, with proper planning and the addition of a programming prerequisite, it is possible to increase the integration of Python as the sole approach to solving numerical problems students are expected to tackle in an OM course.

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KNOWLEDGE NETWORK MANAGEMENT AND SUPPLY CHAIN FIRM PERFORMANCE: EVIDENCE FROM RETAIL (GROCERY) IN TWIN CITIES OF PAKISTAN

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Abstract: This study's main purpose is to analyses the impact of knowledge network management on supply chain practices and supply chain firm performance in the retail grocery sector of the twin cities of Pakistan and to show how knowledge management skills affect supply chain management practices. The objectives are to discover how knowledge network management capabilities, sharing, acquisition, and storage effects supply chain performance in Pakistan's retail industry of Twin Cities. Moreover, to boost the Twin Cities of Pakistan's retail performance and supply chain, However, to improve retail performance along with the supply chain in the Twin Cities of Pakistan, Different techniques, such as testing the suggested hypotheses and all the regression analysis and correlation analysis related to knowledge network management and supply chain firm performance, were performed with SPSS for Windows (IBM SPSS Statistics; Version 26). However, knowledge network management capabilities—sharing, acquisition, and storage—are the independent variables, and supply chain practices mediate with supply chain firm performance as the dependent variable. The supply chain score model to evaluate supply chain firm performance and research constructs A questionnaire survey with self-reported ratings is developed with a five-point Liker scale. The findings of the current study particularly apply to the retail grocery industry because of the specific nature

Keywords: Knowledge network management, Supply chain management, Supply chain Performance, Organization Knowledge network management Capabilities, Sharing.

1. INTRODUCTION

Companies nowadays must adapt to a world of business that is defined by rapid change, technical breakthroughs, shifting customer expectations, and increased rivalry (Bolivar-Ramos et al., 2012; Jagannath et al., 2013). In addition, businesses try to improve their efficiency and edge over the competition by implementing innovative business strategies such as total quality management, the just-in-time methodology, business process reengineering, and supply chain management (Saad and Patel, 2006).

As competition shifts from individual enterprises to supply chains, implementing effective management (SCM) as a means of establishing a significant advantage and boosting organizational performance has become increasingly important in today's business world (Trkman et al., 2010). Globally, firms in both the service and industrial sectors have adopted SCM as their primary operational paradigm (Samuel et al., 2011). Even though SCM has received a lot of attention, experts still don't know for sure what factors contribute to a supply chain's success and failure, especially when it comes to the less physical factors (Hult et al., 2006).

Knowledge management (KM) identifies usable knowledge for strategic planning and promotes global availability and accessibility of important knowledge at the appropriate time to the right person, adding value through its contribution to goods, processes, and people (Akhavan et al., 2009; Tseng, 2010). Consequently, SCM relies heavily on KM, and experts think that a holistic KM strategy can greatly improve SCM's success rate (Samuel et al., 2011). (Shaw et al., 2003; Wadhwa and Saxena, 2005). There has been a lot of interest in studying KM in both the academic and business worlds (Kim et al., 2003), but most of the studies have taken an internal rather than external approach (Samuel et al., 2011). Although several studies have looked into how KM affects firm-level performance (e.g. the ones conducted by Choi et al., 2008; Xiao, 2010), This research uses a structural equation modelling (SEM) approach to examine the effect of knowledge management (KM) processes on supply chain management according to the Supply Chain Operations Citation (SCOR) model, thus helping to fill this knowledge gap. Furthermore, the moderating role of three crucial constructs—support for information systems and IT, supply chain performance, and supply chain strategy—are investigated. This paper will be organized as follows. The theoretical concerns about KM processes, the SCOR model, and or the moderating influence of these constructs are reviewed in Section 2, along with past research on the significance of Km with its possible impact on the performance of supply chains. In Chapter 3, we learn about the study's methodology, which includes the study's model, hypotheses, and data gathering procedure. Part 4 presents the findings from the data analysis, while Section 5 discusses the findings, their managerial implications, the limits of the study, and makes suggestions for further research.

Knowledge management's end goal is to design systems that streamline the process of getting the right information to the right person at the right time through the right medium (Halawi et al., 2006). Knowledge management may also assist firms compete by allowing them to learn about and share the products, services, ideas, and best practices of their rivals with external collaborators (Kyobe, 2010). Knowledge management would also help companies find, analyses, and use information from outside the company (Chuang, 2004; Ju et al., 2006). Supply chain management is one method used to improve business performance and sustain a competitive edge because of the increased intensity of competition between supply networks as opposed to between individual businesses (Li et al., 2006; Ou et al., 2010; Attia 2015; Attia 2016a; Attia 2016b).

The implementation of knowledge management strategies can improve an organization's performance (Yang and Chen, 2009; San-Valle et al., 2011; Jasti et al, 2014). To boost performance and survive in today's cutthroat market, organizations need to collaborate with supply chain partners at all stages (Huo, 2012; Xu et al., 2014). The capacity to effectively handle knowledge is recognized as a crucial strategic resource for supply chain coordination and integration (Rasheed et al., 2010; Abdul Wahab and Sarabi, 2011; Samuel et al., 2011; Tan and Cross, 2012; Xu et al., 2014). Although knowledge management and control of supply chains have been shown to improve organizational performance, only a small number of researches have examined these relationships (Wong and Wong, 2011).

It is essential for companies to be able to make use of this asset in order to gain a lasting competitive advantage. Strategic supply chain management creates value for consumers and other stakeholders (Blome et al, 2014). Yet, the level of intelligence present and how well it is maintained is significantly dependent on the success of achieving a long-term comparative gain in SCM.

In actuality, many international supply chains are impeded by disconnection, disconnection, or other forms of inefficiency and hence fail to operate as efficiently as they could. The health of any supply network depends on knowing how such components interact with one another. While there is a wealth of data on KM for SCM, very little of it has addressed KM in the wider context of supply lines (Schubert & Legner, 2011).

1.1 Research Gap

The field of knowledge creation (KM) has received significant attention from academic and professional researchers alike as a result (Kim et al., 2003), however the vast majority of the investigations conducted have focused inward rather than outward (Samuel et al., 2011). While several studies have examined the impact of KM on the performance of individual companies (e.g., the works of Choi et al., 2008; Wang, 2010), to the best of our understanding, no one has ever conducted a systematic analysis of the impact of KM on supply chain performance. Given the interdependence between company and chain performance results, Hult et al. (2006) argue that it is surprising that this connection hasn't received greater attention. This paper addresses this gap by using a Supply Chain Operations and Reference (SCOR)-based regression model to investigate the impact of knowledge management (KM) processes on supply chain performance.

1.2 Research Objective

1. To determine the impact of Knowledge Acquisition on Supply Chain Firm performance in Retail Sector Twin cities of Pakistan
2. To determine the impact of Knowledge Sharing on Supply Chain Firm performance in Retail Sector Twin cities of Pakistan
3. To determine the impact of Knowledge Storage on Supply Chain Firm performance in Retail Sector Twin cities of Pakistan
4. To determine the impact of Knowledge Capacity on Supply Chain Firm performance in Retail Sector Twin cities of Pakistan
5. To determine the Mediating Impact of Supply Chain Practices on relation between Supply Chain Firm performance and knowledge Network Management in Retail Sector Twin cities of Pakistan

1.3 Research Questions

1. Does Knowledge Network Management Positively Influences Supply Chain Firm Performance in Retail Industry of Twin City of Pakistan.
2. Does Knowledge Capabilities Positively Influences Supply Chain Firm Performance in Retail Industry of Twin City of Pakistan.
3. Does Knowledge Sharing Positively Influences Supply Chain Firm Performance in Retail Industry of Twin City of Pakistan.
4. Does Knowledge Acquisition Positively Influences Supply Chain Firm Performance in Retail Industry of Twin City of Pakistan.
5. Does Knowledge Storage Positively Influences Supply Chain Firm Performance in Retail Industry of Twin City of Pakistan.
6. Do Supply Chain Practices Mediates the relation between Knowledge Network Management and Supply chain Performance of Retail Industry in twin city of Pakistan

2. THEORETICAL BACKGROUNDS OF THE STUDY

Knowledge management in supply chain management is a topic that has received more attention from academics recently. Several academics have postulated that supply chains can benefit greatly from a greater emphasis on knowledge as a strategic asset (Halley and Beaulieu, 2005; Chen et al., 2009; Rashed et al., 2010; Abdul Wahab and Sardabi, 2011; Samuel et al., 2011). Both physical assets and resources, such as those found in machinery, and immaterial ones, like expertise, are part of the intangible assets that make up a well-integrated supply chain (Wu, 2008; Wong and Wong, 2011).

Researchers have looked into the impact of knowledge management on supply chain management and have come to the conclusion that it is beneficial. Yet, there has been a lot of research into this connection from many angles. Li et al. (2012), for instance, provided evidence that improved supply chain integration or supply chain knowledge quality in six manufacturing industries are the result of collaborative knowledge management practices (such as, knowledge creation, storage, access, dissemination, and application). The competitive performance of leading manufacturing enterprises across 24 nations was studied by Chen et al. (2009).

The supply chain's potential for value creation rests on the shoulders of the designers and the managerial choices made regarding the chain's structure, flow, and stakeholder groups. The ability of a business to innovate, adapt to shifting market conditions, and provide new products and services are all factors that can be affected by management decisions. Individuals that excel at it acquire a competitive edge, which in turn boosts their company's long-term success. According to the study's definition of SCM, "a set of approaches – to deliver, manufacturers, storage areas, and stores, so merchandise is manufactured and sent at the required proportion, to the right locations, as well as the right time in order to minimize system wide expense whilst still satisfying service level requirements," SCM is a means by which a business can reduce its overall costs and better meet customers' needs. It was found that (Simchi et company, 2008).

In Porter's (1985) Provision of Products [1985], the supply chain plays a central role. Organizations, according to Porter's model, are not merely a collection of random resources and capabilities; rather, these resources can only add value if arranged in a uniform way, and businesses that effectively manage the connections between their many functions will enjoy a substantial competitive advantage. In addition to Porter's model, Treacy, Wireman offer a helpful method for thinking about how to place your company in the market and create a workable business model, all of which are interconnected with your choice of investments, resources, and warehousing and distribution (Shih et al, 2012). There are often competing goals at different points in the supply chain network, making the supply chain a dynamic and complex set of interconnected activities and processes. Hence, effective methods must be fully integrated throughout the entire supply chain, which means that designing supply chain decisions cannot be made in a vacuum. Designing a successful SC strategy necessitates taking into account combined product and production system design, as argued for by Fine (2000).

According to Lyons and Ma'aram (2014), a competitiveness from a firm's SC configuration requires close alignment between company strategy, SC strategy, and market requirements. The expanding corpus of literature highlighting the importance of linking SC and business strategies emphasizes the importance of integrating and taking a holistic view when making decisions. A study by Von et al. (2014).

2.1 Knowledge Management

Modern supply chains have been recommended by research to use KM instruments to improve quality and efficiency (Gunasekaran & Ngai, 2007). To stay competitive in highly competitive environments, businesses should priorities improving their KM capacity. These organizations are more likely to consolidate vital resources and achieve comprehensive effectiveness (Hsu & Sabherwal, 2011). The purpose of communal KM practices is to facilitate intra- and cross-progressive KM, and to leverage expertise and insightful assets in a coordinated fashion (Cormican & O'Sullivan, 2003). Based on the research of Cormican and O'Sullivan (2003), community KM activities can be understood as systematic, cross-supply chain efforts to create, organize, and use knowledge for the purpose of driving improved business outcomes.

2.2 Knowledge Sharing

In addition, a trade channel's characteristics impact information exchange among supply chain partners (Tsai, 2002). On the flip side, we identified the "berries" of information sharing as a lack of expertise, a lack of time, and originality. in order to follow the instructions.

2.3 Knowledge Acquisition

Knowledge cannot generate hierarchical characteristics on its own, but the manner in which this is applied to produce meaningful outcomes and to take actions that benefit an organization may. Knowledge implementation in the supply chain improves and reinforces the sharing of knowledge and information amongst all participants. The organization's capacity to organize and apply the state of the art in knowledge to authoritative tasks and discriminatory inference is a key area that information management methods should streamline and enhance. But it is not the methods by which learning is obtained, saved, and disseminated, but rather its practical application, that causes a rethinking of official behavior (Alavi & Leidner 2001).

2.4 Knowledge Storage

The way in which information is employed to generate meaningful outcomes and conduct actions that assist the organization has an effect, even though knowledge could generate hierarchical qualities on its own. Knowledge adoption is applied to the production process in order to enhance and fortify the flow of information and knowledge amongst all parties involved. Businesses can benefit from better coordination and use of knowledge in authoritative exercises and selective inferences if they implement information management practices (Grant, 1996). While it's crucial to have efficient systems in place for gathering, sorting, and sharing data, what really matters is what's done with that information once it's been gathered (Alavi & Leidner 2001).

2.5 Supply Chain Performance

The supply chain, which is not a specific industry but rather a unit of competitiveness in the modern world, has been highlighted as a new analytical unit for best business practices. Handfield (2002).

Martinez et al. (2010) report that business leaders realize they cannot compete successfully without their suppliers and other entities in the production process. Thus, instead of focusing on rival companies, they are now thinking about rivals inside their supply chains as a whole. A supply chain's breakdown can be triggered by dissatisfaction with its performance, which leads to localized disasters (Ntayi & Eyaa, 2010). In order to maximize effectiveness and efficiency, numerous scholars have proposed a wide variety of frameworks and dimensions for SCP (Lin & Li, 2010). Supply chain success was evaluated using the performance measures presented by Aramyan et al. (2007). In order to assess SCP, the literature identifies four key indicators of performance: speed, efficiency, adaptability, and quality (either product or process). It has been widely acknowledged that SCM can help businesses acquire an edge in the marketplace, as stated by Barney (2012). SCP is a technique for evaluating the potential and value of chains. If SCP is to be effective, it must ensure that the appropriate item is delivered at the right time and at the lowest possible cost. There has been a dramatic uptick in performance evaluation during the past two decades (Taticchi, Tonelli, & Cagnazzo, 2010)".

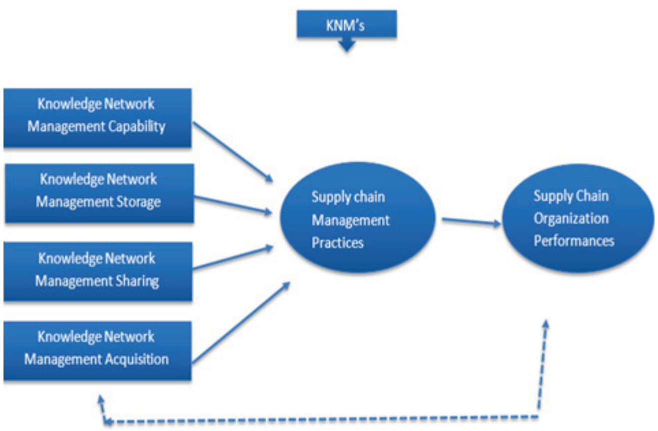

Figure 1 Theoretical Framework of The Study

2.6 Knowledge Management Capability and Supply Chain Management Practices

Knowledge management in supply chain management has gained more attention from academics recently. Many scientists have the opinion that, one of the most important strategic assets that could help supply chains succeed is knowledge (Halley and Beaulieu, 2005; Chen et al., 2009; Rashed et al., 2010; Abdul Wahab and Sardabi, 2011; Samuel et al., 2011). Both physical assets and resources, such as those found in inventory, and immaterial ones, such as expertise, are part of the intangible assets that make up a well-integrated supply chain (Wu, 2008; Wong and Wong, 2011).

Knowledge management has been the subject of much study, and the findings have consistently shown an improvement in the handling of supply chains for businesses who employ it. This connection, however, has been studied from numerous angles. Evidence was shown by Li et al. (2012) and others that demonstrates how collaborative knowledge management strategies (such as knowledge production, storage, access, distribution, and application) improve supply chains and supply chain knowledge quality.

In fact, Sambasivan et al. (2009) looked into the connection between supply management learning and organizational productivity in Malaysian manufacturing firms, as well as the role that organizational knowledge and knowledge application had in each. They theorized that supply chain members should study together to create and apply knowledge effectively. Knowledge acquisition, data conversion, knowledge application, and knowledge protection are all aspects of supply chain knowledge creation that Schoenherr et al. (2014) recently analyzed in a survey of 195 U.S. small and medium-sized businesses. They reasoned that a dynamic capacity like supply chain performance management may boost supply chain performance and improve decision-making.

The SCOR framework The SCOR model (Lai et al., 2004) is a framework for discovering, analysing, and monitoring the success of supply chains by bringing together performance indicators, processes, best practices, and people. SCOR is the only approach that can be used across industries and that accounts for the full spectrum of sourcing maturity, from the individual company to the global community (Estampe et al., 2013). These are the five main supply chain procedures that it sees as necessary to achieve the goal of delivering client orders (Supply Chain Forum, 2010):

(1) Plan: the acts of planning involved in running a supply chain, such as determining where to get what you need, making it, delivering it, and taking it back, managing your demand and supply, finding out what you have on hand and how much you need, and balancing those two.

Identification and selection of supply sources; placing purchase orders; scheduling deliveries; receiving; validating and storing shipments; accepting supplier invoices; managing inventory; and managing capital assets; incoming items; supplier networks; and supplier agreements.

Managing work-in-progress items, manufacturing performance, equipment's, and facilities, as well as delivering finished goods to customers are all part of the "Make" phase of the product life cycle.

Delivering goods to a consumer includes four main steps: (4) receiving and picking orders, (5) loading and shipping goods, and (6) transporting goods to the customer for final verification. Fifthly, "Return" refers to all the processes involved in sending supplies (raw materials) back to the manufacturer and finished goods to the retailer. The impact of Knowledge Management methods totaling 607 We don't look into the Return process, even though the KBV lays the groundwork for understanding the connection between KM and it. The Return process isn't as well-developed or institutionalized as the other four supply chain processes (Zhou et al., 2011; Bronzo et al., 2012). As a result, we focus primarily on the effects of KM activities on effectiveness in the areas of "Plan," "Source," "Make," and "Delivery".

3. METHDOLOGY

This section provides an overview of the study topics, a definition of the analytical methods employed in their description, an explanation of the questionnaire's construction, a detailed description of the sample, and a rationale for how the sample was collected. The features and specs are as follows: The features of the samples and indeed the collection techniques, as well as the questionnaire's nature, research questions, and statistical analysis, are discussed in this chapter.

3.1 Research Design

The purpose of this study was to examine a hypothesized relationship between knowledge chain management and performance of supply chain firms operating in the retail sector of Pakistan's twin cities. According to the findings of Sekihan and Boogie (2010) shows that a number of factors have an effect on the issue (SC business performance) and each other; the expert may be asked to identify the most crucial ones. So, the researcher investigated how the ability to manage knowledge networks affected the efficiency of supply chain businesses. Thus, a correlational study design was used for this analysis. As part of the regular course of work, the specialist conducted this investigation within the shared territory of the organization with minimal disruption. As a result, the inquiry was conducted in an unstructured environment.

3.2 Sample Data and Population

If the demographic is randomly picked, then there is a 100% chance that any given person in that group will be included in the sample (Gravetter et al., 2011). Using a random sampling procedure is advantageous because it removes the potential for bias in the screening process and should yield samples that are truly representative of the population as a whole. A size of the sample of several hundred is recommended for successfully implementing the fundamental random strategy in practice. It has been said that while the idea behind this strategy is straightforward, putting it into practice is far more difficult. So, it may be challenging to determine an appropriate sample size when working with a sizable data set. As a result, we chose 150 shops at random from the two largest cities in Pakistan.

Information was collected from 150 stores in the two locations. The stores were chosen to represent a range of sizes in the retail sector. As a result, stores would provide data for the study over a limited time window.

Primary data were used extensively for this investigation. It was decided to collect data using the method outlined by semi-structured forms. We used a five-point Likert scale ranging from vehemently disagree to wholeheartedly agree. Questionnaires were sent out to all of the representatives in the sample in order to get an accurate read on the KNM capacity and SC company performance. The original version of the survey was developed in English.

This particular dataset is based on a survey of shops in Pakistan's two largest cities. In order to determine the minimum sample size, many scholars have suggested use a ratio of five to ten reports per indicator variable (e.g., Hair et al., 2006; Kline, 2011). There are 22 indicators in the designed framework (four KM stages and procurement process), thus a sample of 300 branches is enough and in line with the specified minimum sample size.

3.3 Instrument Development

A self-reported rating questionnaire is developed for the research constructs. A modified version of Steele's (2003) evaluation method is used to assess the KNM capacity; specifically, four unique KM processes are each analyzed using a set of four correctly stated statements. This tool has been used and validated in a plethora of previous research (e.g., Ramachandran et al., 2009; Allameh et al., 2011). The models were all developed using a five-point Likert scale with 1 indicating strongly objecting and 5 indicating strongly agreeing. This idea is supported by practitioners, and it is consistent with the findings of other studies, such as Trkman at al. (2010) et Zhou & al. (2011), which discovered that the retail sector did not dispute any of the SC important processes including the return process.

3.4 Sources of Data

The research will collect the inviting article through the use of search engines like Google, following the pattern of a review of previously published material. Together with the scholarly publications, a questionnaire will be sent out to all of the sampled retail establishments in the twin towns in Pakistan to see how knowledge network management competency affects supply chain practices and procurement firm performance.

3.5 Research Nature

The study's goal is to examine how knowledge network management competency affects supply chain practices and supply chain company performance in the retail sector in Pakistan's twin cities. It is clear that a workable research model was necessary to accomplish the study's goals. This framework explains the methods used to collect and analyses data in order to draw conclusions. The effect of education will be studied systematically Impact of network management competence on supply chain procedures and supply chain business effectiveness in Pakistan's twin cities' retail sector. Methodology details, including data collection procedures and sample selection criteria, are presented in this section of the research.

4 DESCRIPTIVE STATISTICS

4.1 Demographic Profile of Respondent

Table 1 demonstrates that all of the participants in the study were men (150 out of 150). In accordance with the numbers presented in the following table, 30% of participants are between the ages of 20 and 30, indicating that a considerable number of persons of this age work in retail. Following the age limit of 31-40 years, which comprises 33% of the study population, 39 respondents are between the ages of 18-25 years, and among the remaining 150, 7% are between the ages of 41-50 years, and 3% are between the ages of 50 and above years. It is also demonstrated in Table 1 that the majority of those surveyed are undergrads, representing approximately 50% of the research population, with 40% having graduate degrees, indicating that the retail market has a significant number of educated people and that those workers are enjoying a good income level. As shown in Table 1, 40% of respondents have an income level between $101,000 and 150,000, with only six having an income level of 150,000 or higher.

Additionally, the table demonstrates the range of store sizes. Of the respondents in this study, 30 are employed in large stores (stores with more than 10 employees; 20%), 47 work in" "medium-sized stores (stores with 6 to 9 employees; 47%), and 50 work in small stores (stores with fewer than 5 employees) (stores where there are 5 employees or less).

Table 1: demographic profile

	Frequency	Percentage
Age		
18-25	39	26%
20-30	45	30%
31-40	50	33%
41-50	11	7%
51 years and above	5	3%
Gender		
Male	150	100%
female	00	0%
Qualifications		
Matric	35	23%
Undergrads	75	50%
Graduates	40	27%
Income in rupee		
PKR 20000-50000	33	22%
PKR 51000-100000	50	33%
PKR101000-150000	61	41%
PKR 151000and above	6	4%
Size of the store		
Small	50	33%
Medium	70	47%
Large	30	20%
No. of workers		
Less than 5	50	33%
5-10	70	47%
10 and above	30	20%

4.2 Reliability Analysis

Table 2: Reliability

Items	Cronbach's alpha
Knowledge Network management capability	0.850
Knowledge Network management sharing	0.821
Knowledge Network management storage	0.799
Knowledge Network management acquisition	0.901
Supply chain management practices	0.801
Firm performance	0.831

4.3 Correlation Analysis

Correlation analysis can be employed to figure out the existence, strength, and direction of a linear relationship between the various variables in the model. In this context, a positive correlation exists across all of the study variables in the model, as determined by the 99% confidence level generated by the correlation analysis results (Table 3). Knowledge management capability was discovered to have a favorable correlation with supply chain management practices and with SC firm performance, and supply chain management practices were revealed to have a good correlation with SC firm performance as well.

Table 3: Correlation matrix

Items	1	2	3	4	5	6
1	1					
2	0.392	1				
3	0.242	0.301	1			
4	0.411	0.399	0.401	1		
5	0.488	0.421	0.381	0.377	1	
6	0.611	0.598	0.501	0.513	0.492	1

Note: Correlation is significant at *0.01 levels (two-tailed).

4.4 Regression Analysis

To examine the impact of the independent variables on the dependent variable, a regression analysis was performed. While knowledge network management capabilities, knowledge sharing, knowledge storage, knowledge acquisition, and supply chain practices are treated as independent variables in this research, firm performance in the supply chain acts as the dependent variable.

Table 4 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.7968	0.6349	0.6106	0.0003

In accordance with the findings of the variance analysis (ANOVA), shown in Table 5, the F value of 23.39 is highly significant at 0.000, indicating that demographic variables have a substantial influence on the supply chain firm performance in the retail market of Pakistan's twin cities."

According to the results of the analysis of variance (ANOVA), shown in table 5 above, the sum of the squares for the regression is 435.265, with a df value of 15. The calculated mean square value of 29.01 is more than the minimum value of 19. Ultimately, a p-value of 0.000 indicates a highly significant relationship between the two variables, such as supply chain firm performance, knowledge network management capabilities, and supply chain practices.

Table 5: ANOVA Summary

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	435.265	15	9.01	3.39	0.000
	Residual	504.583	406	0.24		
	Total	939.849	421			

Table 6 shows the analysis of the analysis of the explanatory variables of knowledge network management capability and supply chain firm performance and their effect on retail market in twin cities of Pakistan. Therefore, in order to observe the effect of knowledge network management capability on supply chain firm performance a multiple liner regression model was developed. The supply chain firm performance was taken as dependent variable, meanwhile knowledge network management, knowledge sharing, knowledge storage, knowledge acquisition, was taken as independent variable along with supply chain practices as mediator. The result of all stepwise regression analysis shows that all the variables have significant effect on the supply chain firm performance on retail market.

Statistic 2.321 and significance level is 0.008, which is fewer than P-value 0.05 and the Beta value (ß=.286, sig<.05) is the utmost significant after that supply chain practices with Beta value (ß=.277, sig<.05), t-statistics 2.791 and significant at 0.001.

Furthermore, statistics has revealed the third influential variable with t-statistics 1.970 and significant at 0.005, also the Beta value (ß=.226, sig<.05) shown the percent of variation in dependent variable if supply chain firm performance changed by 1%, then it after that knowledge storage (ß=.292, sig<.05) and are significant at 0.000 correspondingly."

Table 6: Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
Model Indicator	B	Std. Error	Beta	T	P. Val
(Constant)	3.869	0.578		6.693	0.000
SC firm performance	0.527	0.173	0.298	2.321	0.008
KNM capability	0.538	0.221	0.286	2.394	0.017
Knowledge sharing	0.412	0.155	0.021	2.260	0.024
Knowledge storage	0.428	0.122	0.292	3.501	0.000
Knowledge acquisition	0.461	0.234	0.226	1.970	0.005
SCM Practices	0.535	0.191	0.277	2.791	0.001

5 DISCUSSION AND CONCLUSIONS

According to the previous results the knowledge management capabilities play a major in improving the supply chain management practices. Thus, H1 is accepted. This result is consistent with that of previous studies for example (Wong and Wong 2011; Youn et al., 2013). Knowledge management capabilities are considered a driver and key success factor in supply chains (Rashed et al., 2010; Samuel et al., 2011). Wong and Wong (2011) provided evidence that knowledge management capabilities (including technology and processes) would influence supply chain management practices. They concluded that knowledge management capabilities enable knowledge sharing among the employees as well as between organizations. In addition, they facilitate information sharing, cooperation and long-term relationships among supply chain members, which would result in creating value-added products and services to the customers.

Similarly, Dalpati et al., (2010) proposed that sharing knowledge between supply chain members can speed up the flow of knowledge in the supply chain, improve the efficiency and effectiveness of the supply chain, and enables the organizations to respond quickly to customers changing needs. In addition, Youn et al., (2013) argued that effective information sharing among supply chain members requires mutual trust, top management support as well as organizational compatibility.

The current study has four principal limitations, all of which present opportunities for future research. First, the current study focused only upon the Saudi food industry; therefore, there is a need to re-study the hypothesized relationships between the variables in different retail industrial of Supply chain sectors and in different developed cities of country. Second, the impact of other internal practices and factors on the hypothesized model need to be considered and tested in different industries and countries. Third, there is a need to collect data from more respondents within the Saudi food industry (the present study collected data from only 165 respondents from a total of 732 companies in this industry) to generate more representative results (Jasti and Kodali 2014). Finally, it would be useful to repeat the study's methodology by collecting data from multiple supply chain partners, rather than only from the buyer or the focal firm.

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PQCDSM-Logic in Maintenance (TPM) and Mountaineering

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TPM is the foundation for JIT (Just in Time) and Lean Manufacturing and forms the basis of JIT or on-time delivery. The goal of TPM is to improve equipment effectiveness and optimize equipment performance, namely PQCDSM (Productivity, Quality, Cost and Delivery, Safety and health, environment, and Morale). Many producers have tried to transform their production system to a JIT or Lean production system with the aim of increasing productivity and quality, but thus far with little success.

This contribution shows how trekking and climbing tours can be used to illustrate the application of PQCDSM-Logic in mountaineering and how this can be trans-ferred to logistics and maintenance practice. The background is the author's decades of experience with expeditions, trekking and climbing tours, TPM implementa-tions and interviews with numerous experts. There are many similarities between the application of PQCDSM-Logic in mountaineering and in logistics and mainte-nance practice, which will help both in operational practice in industry and in high mountain tours, especially regarding safety in a changing environment. Presented is the extrapolation from mountain climbing to TPM and the importance of leadership for a successful (summit climbs and the like) transformation of the production system to a JIT or Lean production system.

Keywords: *environment, equipment, leadership, logistics, PQCDSM, mountaineering, safety, Total Productive Maintenance*

A Returnable Transport Item to Integrate Logistics 4.0 and Circular Economy in Pharma Supply Chains

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Recent global events, such as the COVID-19 pandemic, the war in Ukraine and the climate crisis, force the pharma logistics sector to rapidly improve their processes and establish more resilient and sustainable medical supply chains. For this purpose, the pharma logistics sector needs to catch up in Industry 4.0 adoption and establish circular economies. In the context of the applied research project DigiPharmaLogNet, a prototypic returnable transport item (RTI) is enhanced with communication technology and piloted in pharma-specific use-cases. The results will build the base for developing business models and roadmaps towards sustainable pharma logistics networks. This article describes the technological developments and economical evaluations of potential business models.

Keywords: *Pharma Logistics, Pharma Supply Chain, Sustainable Development Goals, Industry 4.0, Circular Economy, Reverse Logistics*

Digital Supply Chain Twins in Urban Logistics System – Conception of an Integrative Platform

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Current trends in urban areas pose several challenges to city logistics stakeholders while also offering opportunities for optimization. With its analytics, modelling and simulation capabilities, the Digital Supply Chain Twin (DSCT) technology provides a possibility to optimize urban logistics processes. However, a number of barriers have limited the implementation of holistic DSCTs so far. An integrative, collaborative platform could decrease these barriers. By applying design science research methodology and expert interviews, this paper develops an architecture for a high-level cross-institutional platform for the generation of DSCTs. This framework includes a modular design of the platform through eight functional modules. The platform can facilitate the implementation of DSCTs for urban stakeholders and thus optimize urban logistics processes.

Keywords: *cross-institutional platform, design science research, digital supply chain twin, digital twin, urban logistics*

Use of Green Industry 5.0 Technologies in Logistics Activities

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Industry 5.0 is a human-centered concept of industrial development towards the sustainable and resilient system presented by the European Union which aims to become the global both innovation and industrial leader. It should overcome the barriers of the previously presented Industry 4.0. This paper presents the research conducted in the 112 Croatian manufacturing companies, dealing with their awareness level of the Industry 5.0, as well as the use of green and digital elements in logistics activities. The results have shown that the awareness of the digital concept of both Industry 4.0 or 5.0 remains low, but the companies are more open towards the implementation of the green elements than the digital ones, with the potential for future development recognized.

Keywords: *Industry 4.0, Industry 5.0, ergonomics, logistics 4.0, green industry, green logistics, sustainability*

JUST TOO LATE: MISMATCHING ISSUES IN AUTOMOTIVE INDUSTRY

Attila TURI

Abstract: The purpose of this paper was to analyze data from automotive industry manufacturers in Western Romania and source why a high order variation builds up within their short loop supply chains (supplier – manufacturer – customer). Issues with time-consuming procedures, inaccurate performance metrics and high volumes of activity contribute to an increased intensity in order variability as shown by the gathered research data analyzed within 25 weeks for a range of chosen suppliers. Average order variability shifts with more than 30% to the manufacturer's suppliers whereas variability intervals range up to three times as much adding further internal logistics operations issues. Results show an improved induction and training program would help reduce persistent fluctuating backlog-overstock issues by almost 50%, especially within departments where younger and less-experienced internship students and fresh graduates are more prevalent.

Keywords: automotive industry, internal logistics, order variability, out-of-stock (OOS), supply chain

1 CASE DESCRIPTION

The economic importance of the automotive industry (12% of GDP and 30% of exports in 2022) has been rapidly increasing in Romania due to the Dacia and Ford factories, their network of suppliers (more than 500 nationally) and over 230,000 specialized jobs. In the last 20 years production output has increased 100 times, carmakers turnover 50 times and today automotive industry represents 17.5% of the manufacturing industry in Romania. This growth has been enabled by several multinational automotive suppliers setting up facilities here, especially in the Western area [1, 2]. The region is attractive because of its infrastructure network, economic welfare, density of university centers and young dynamic population [3].

Higher volumes, newly launched projects and increasing capacity in addition to a plant already running at full tilt are a common occurrence in the area [4]. The challenges arising are to maintain current operational performance efficient and to smoothly integrate new volumes of activity within a growing team of new and mostly inexperienced new employees [5]. Finding a proper work balance between a wide array of supplier and customer requirements and typical daily logistics issues (urgent shipments, backlog and overstock, delivery issues) while just learning to use a specific information system can prove quite demanding for an intern with lack of experience or basic logistics knowledge [6].

Moreover, the Just-in-Time (JIT) production system's emphasis on keeping minimum inventory while maintaining a lean production flow and continuous pace of the assembly line further adds pressure during their hands-on induction period [7]. A properly estimated forecast will help production planning design its needs accordingly and balance out the potential risks of backlog, stockouts, useless overstock or lugging excessive inventory [8]. The recent Covid-19 pandemic uncertainty, port bottlenecks and semiconductor shortage issue in automotive industry have triggered a reflex of surplus ordering, affecting supplier lead times and delivery reliability as well as increasing safety stock levels by up to 20% [9]. Russia's invasion of Ukraine has generated rising electricity and gas prices, double-digit inflation and some pressures on compensating salary increases, further adding challenges to running a smooth operational performance [10]. Managing automotive industry's global supply chain in such turbulent times makes taking decisions, anticipating trends and running an effective operation a lot more difficult [11].

The objective of the carried out research was to trace and quantify the multiplicative order variation generated within the companies' logistics departments, despite using state of the art information systems, forecasting and planning tools, as well as experienced supervisors [12]. Autonomous interns with no induction and initial supervision, loose performance metrics and high new employee turnover enable the setting for recurring issues [13]. Seeking improvement will be biased and ineffective without addressing root causes, training and integrating apprentices and monitoring relevant KPIs on a regular basis [14]. The topic was chosen as it is very current within the automotive industry (mismatch between high order and material shortage) [15], but in addition is more challenging due to its more unique particularities: orders/volumes growing exponentially, increased material shortage/uncertainty and urging immediate integration of interns within a complex JIT production system. These dynamic characteristics create a high degree of complexity and are more difficult to gauge as a whole than more isolated issues or challenges, as are usually found in the available research.

2 METHODS

The data provided in this research paper was gathered throughout a 6 month period (25 weeks) with relevant company members in order to provide an accurate overview of their logistics activities. The paper focuses on order variations generated internally within the 2 companies towards 10 of their most important suppliers for raw materials, components and parts needed to manufacture their corresponding end products at their production facilities in Western Romania. The aforementioned companies requested several limitations to the extent of the disclosure of the data they provided for this analysis, which are respected within the content of the current paper. Only general or broad mentions of their identity, location and field of activity were consented. Similarly, only parts of the conducted research data, methods and results from the full report received clearance for use. This may cause the reader to reasonably question validity and relevance of certain results and conclusions provided.

Actual customer orders for the 6 months were recorded and compared to the forecasted levels. The forecasted levels for each month were based on the customer estimate and then smoothed exponentially with trend and forecast ($\alpha = 0.3$; $\beta = 0.2$; $\gamma = 0.5$). Both companies agreed a 5% order variation level with their customers where current pricing conditions apply. Actual orders to suppliers for the same period were recorded, averaged out and their variation and maximum ranges calculated (for each supplier, as well as aggregated). Both companies claim their departments work within a Just-in-Time (JIT) system. Data from customer orders is compared to orders made to suppliers within a period of 6 months (June-November), ranging from average order variations to suppliers, maximum variation ranges and overall average variations (only available in relative figures, as percentages). Correlations between distance and lead time, lead time and order variation and between lead time and order variation range within the analyzed suppliers were also sought. However, permission to use absolute data, positive or negative, minimum and maximum references was not granted.

The objective of the conducted research was to analyze what causes variation increase within the logistics departments and to quantify the extent of the issue within the companies' short loop supply chains (supplier – manufacturer – customer). Focus groups were organized to analyze results obtained and discuss the proposed solutions to help improve the organization, performance and efficiency of their logistics department. An approved selection of data (tables and figures) is provided in the following section along with comments, outcomes and interpretations, whilst conclusions are outlined in the latter section of the paper.

3 ANALYSIS

Table 1 presents the order variation transmitted by company 1 to 10 of its most important suppliers within a time span of 6 months. Except for 2 suppliers which are located in Asia, the rest are located in Europe and have an average lead time of 3-6 days. Only 2 suppliers are located in the same European country, the rest are spread out across Europe. Two European suppliers have a longer lead time (10 days), whereas the suppliers in Asia (India and Thailand) have lead time of 2 months. Some of the suppliers have a shorter distance and/or lead time than others, but there is no correlation that can be made between distance and lead time, lead time and order variation or lead time and order variation range within the analyzed suppliers (there is only 1 exception).

Table 1 Order variation from company 1 to its suppliers

supplier #	average order variation from C1 [%]	maximum order variation range, min-MAX [%]
supplier 1	16.91	51.15
supplier 2	35.19	119.42
supplier 3	43.17	131.31
supplier 4	25.86	77.08
supplier 5	41.37	114.69
supplier 6	20.65	87.54
supplier 7	25.00	103.33
supplier 8	29.16	112.50
supplier 9	59.38	222.34
supplier 10	29.89	102.36
overall average (all suppliers)	**32.66**	**112.17**

The overall average of the company's order variation (company 1), made to all of the selected suppliers in those 6 months, is just below 33%. Most order variations to individual suppliers are within 25-30% (4), with some being in the 35-45% range (3) or within a 15-20% range (2), on average. Only 1 supplier has an average order variation exceeding 50% (supplier 9), which is double the average of all other suppliers. The maximum variation range which spans from the highest decrease to the highest decrease is 3-4 times the order variation (3.43, on average for all suppliers). There is no positive correlation that can be made between a high order variation and a higher maximum order range. However since there is an average of 3.43 for the range compared to its order variations, this means that the higher the order variation the company causes the higher the variability will be for the concurrent range generated. For company 1 there are only 3 ranges below 100 percentage points (suppliers 1, 4 and 6), most being within the overall average (6 suppliers) with the exception of supplier 9, where the range (222.34 percentage points) is more than double the average of all other suppliers.

Table 2 Order variation from company 2 to its suppliers

supplier #	average order variation from C2 [%]	maximum order variation range, min-MAX [%]
supplier 1	46.66	150.00
supplier 2	27.67	113.21
supplier 3	19.04	53.06
supplier 4	15.49	54.93
supplier 5	44.91	168.95
supplier 6	40.45	137.75
supplier 7	25.91	88.16
supplier 8	120.00	440.00
supplier 9	71.97	257.96
supplier 10	24.33	70.06
overall average (all suppliers)	**43.65**	**153.4**

Table 2 presents the order variation passed on by company 2 to 10 of its most important suppliers within the same time span of 6 months. Except for 2 suppliers which are located in Asia, the rest are located in Western Europe and have an average lead time of either 5-7 days (4 suppliers) or 10-14 days (4 suppliers). Half of the suppliers are located in the same country in Western Europe, whilst the others are located in neighboring countries (2 of the 3 are from the same country as well), therefore there is a better concentration of these suppliers compared to company 1. Three European suppliers have a shorter lead time (5 days), whereas the suppliers in Asia (China and Malaysia) have lead time of 2 months. Some of the suppliers have a shorter distance and/or lead time than others, but there is no correlation that can be made between distance and lead time, lead time and order variation or lead time and order variation range within the analyzed suppliers.

The overall average of company 2's order variation to its suppliers (in 6 months) is above 43%. Most order variations to individual suppliers are within 25-30% (3), in the 40-45% range (3) or within a 15-20% range (2), on average. Only 2 suppliers have an average order variation significantly exceeding 50%: suppliers 8 with 71.97% and supplier 9, which has more than 3 times the average of all other suppliers. The maximum variation range which spans from the highest decrease to the highest decrease is 3-4 times the order variation (3.52, on average for all suppliers), similar to company 1. No positive correlation can be made between a high order variation and a higher maximum order range (same as for company 1). An average of 3.52 for the range compared to company 2's order variations means that the higher the order variation the company causes the higher the variability will be for the subsequent range (same as for company 1). For company 2 there are 4 ranges below 100 percentage points (suppliers 3, 4, 7 and 10), another 4 being within the overall average (suppliers 1, 2, 5 and 6). There are only 2 exceptions: supplier 9, where the range (over 250 percentage points) is almost double the average and supplier 8 (almost 450 percentage points), where the range is 3 times higher than the overall average.

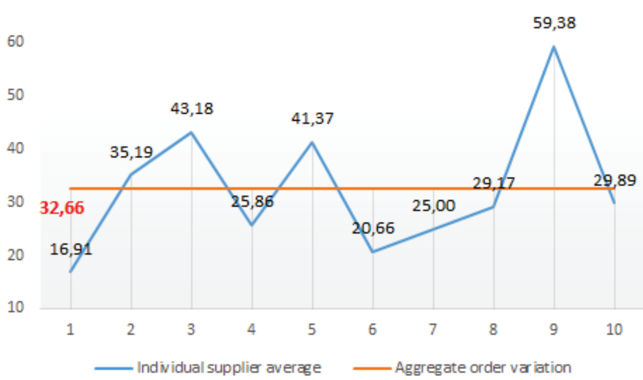

Figure 1 Average order variation to supplier, C1 [%]

Figures 1 and 2 present the average order variation to supplier for companies 1 and 2 separately, whereas in figure 3 these variations are overlapped. The variations observed for company 1 (red) are more sinuous, but they follow a more compact spread along the orders for the corresponding suppliers. On the other hand, variations for company 2 (yellow) are more extreme when compared to the average and follow a more disrupted pattern for the orders sent out to their suppliers.

Company 1 sells 2 types of automotive products to a wide range of customers. These products are rather classical car components and have a rather standard manufacturing process with some elements of variety and customization demanded by customers coming towards the end phase. New technology and prices have been increased proportionally, whereas cost has been rather stable as there is a trade-off between economies of scale of the production process and the need for specialized workforce.

For its internal logistics organization the company has chosen a vertical approach with its 2 main departments (for each product range), as each customer gets a dedicated team allocated which handles the entire process (supplier order – manufacturing process – customer delivery). The specialists from across departments and areas (customer orders, production planning and supplier sourcing) thus work on parallel projects and their workload mainly depends on the specifics of one particular customer and their orders, issues and new projects. Each team will get very familiar with a specific customer and their ability and capacity to seamlessly handle ongoing projects and issues will normally avoid stopping the production line (own and customer). There are separate departments handling warehousing (inventory accuracy and packaging requirements) and transportation (both inbound and outbound) which have a more hybrid approach, some dealing with only a specific customer (higher volumes) while others handle several customers (aggregating those with lower volumes).

In terms of data accuracy (in stock, in delivery, work-in-progress, end of day inventory), company 1 uses an automatic report issued to all concerned departments in case there are missing parts, in order to adjust and update planning schedules. Since workload is higher than warehouse capacity at full capacity, the company uses a schedule for reception and warehouse space allocation. If it is not enough, external warehousing spaces are used for temporary storage of goods before being retrieved in its own warehouse prior to being used in production. Orders are sent automatically through the system to suppliers after being checked and approved by those in charge of placing those orders.

As shown in table 1, the variation of orders (overall average to all suppliers) was 32.66%, but the variation of orders received from customers for the corresponding materials (overall average) was only 5.43%. This means that the variation sent to company 1' suppliers was 6.01 times higher than the one received from its customers. The company has an agreed level of orders and if the agreed and scheduled quantities are exceeded by more than 5%, new pricing conditions apply. The customers analyzed had a range of orders exceeding agreement levels between 4.35% and 6.17%, only 3 managing to stay within the agreed interval.

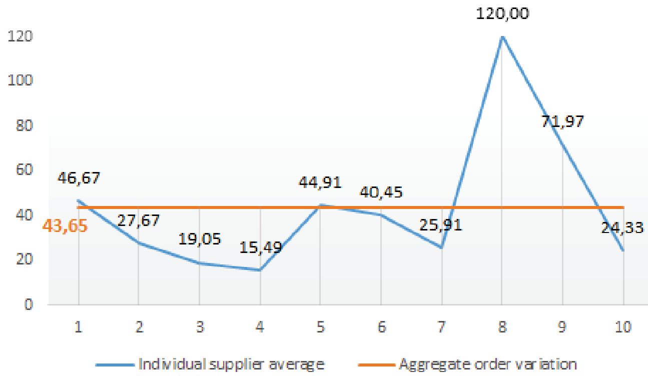

Figure 2 Average order variation to supplier, C2 [%]

Company 2 has chosen a horizontal approach for its internal logistics organization, divided among its 2 main departments (for each product range). Each department will have a dedicated team handling one specific phase of supply chain management: material planning (supplier orders), production planning (manufacturing), customer planning (customer orders and service) and new product launch (implementing new projects within the existing structure). Specialists from each department work on all projects together and their workload is aggregated among all customers, being more challenging as the specifics of each customer and their orders, issues and new projects are quite different. High attention to detail is needed, as well as very organized and focused work discipline in order to properly keep track of all ongoing projects, as well as issues and avoid stopping the production line (own and customer). Warehousing is a separate department and is responsible for inventory accuracy (updating inbound and outbound flow of raw materials, finished goods and component availability). Another separate department is transportation for both inbound (incoming raw materials and parts) and outbound (delivering finished goods to customers). These departments are more flexible as they may work on dedicated projects (parallel) or on several ones (aggregate), more similar to a hybrid approach.

In terms of data accuracy, company 2 has some issues with backlog (parts not delivered by suppliers or no receipt confirmation upon arrival to warehouse). A report is issued only to the material planner if there are missing parts, but he has to inform his colleagues from production before they can adjust planning schedules. Confirmation e-mails are used to keep track of these issues. Warehouse workload is constantly at full capacity and there is a priority system used, based on emergencies (the most urgent is handled first), regardless of type: customer delivery, return-to-vendor, intra-company shipping or regular reception from suppliers. The company uses time slots to schedule for reception of trucks at their warehouse, but even emergencies have to be registered in the system before being unloaded. Storage capacity has been improved, but external spaces are also available, if needed. Supplier orders are sent automatically each week through the system, the only manual intervention occurs in case a higher quantity is needed or if the delivery date needs to be advanced.

Table 2 showed a variation of orders (overall average to all suppliers) of 43.65% for company 2, but the variation of orders received for the corresponding materials (overall average) from its customers was only 3.98%. This means that the variation sent to company 2' suppliers was 10.94 times higher than that received from its customers. As per contract, new pricing conditions apply if variation levels exceed 5%. The customers analyzed had a range of orders exceeding agreement levels between 1.61% and 6.45%, only 3 not managing to stay within the agreed interval.

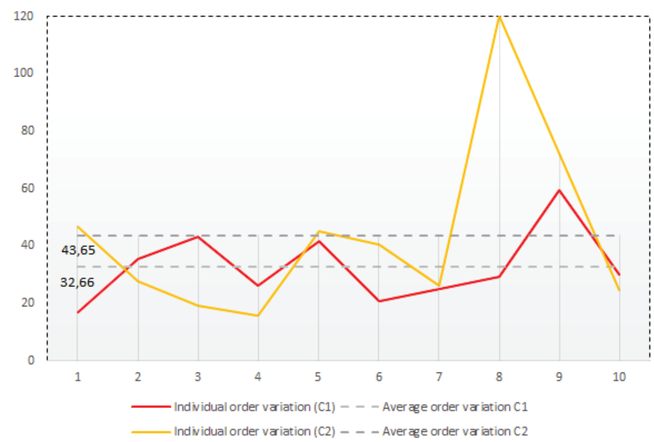

Figure 3 Average order variation to suppliers, C1 and C2 [%]

Company 2 has a higher average order variation (+33.62%) as well as a higher order variation range (+36.76%), despite incurring a lower customer order variation (-26.55%) than company 1.

Company 2 has a very young staff employed within its logistics department, mostly students in internship or on a bachelor degree program (4-6 months), fresh graduates or students enrolled in a master degree. These students may have some background knowledge, but there is a lack of mentorship and integration within their jobs and they mostly rely on the help of their colleagues, who are also faced with many tasks. Thus there are a lot of errors being passed on, mostly by the lack of understanding on how the process works, which are somewhat reduced by a team leader occasionally when aggregating monthly orders and reports due for some meetings and sometimes some comments are made. The biggest challenge is to how the new recruits understand the balance between not ordering enough (causing backlog, stockouts or worse: stopping the production line) and ordering too much (causing overstock, congesting the warehouse and increasing workload unnecessarily). Most of the time, they will order too much in order to avoid stopping production due to lack of material. This however will cause the reverse effect, as constantly ordering too much creates an even bigger issue: longer lead times, incomplete orders, more expensive transportation costs and an even higher chance of stopping the production line.

When ordering more, more time is needed to produce a higher quantity, which will ultimately increase lead time from certain suppliers (longer supplier lead times). Constant pressure on increasing quantities (6 times on average compared to customer order variation) may lead to potential and occasional shortages due to increased order size which the supplier may not be able to fulfill in due time, generating backlog due to incomplete orders arriving (incomplete orders also mean a new shipment has to arrive at a later date and be unloaded – more work for the warehouse). In case some parts are absolutely needed, in that precise quantity, then special transports will be organized in order to speed up shipping, which will in turn increase transportation costs and make these errors more costly to the company. If the special transport can get the products to the factory line faster and in due time (inbound), then production can keep its pace and source the scheduled finished goods to be delivered to customers. However, if this is not the case another special transport needs to be organized for customer delivery (outbound) in order to compensate for the delay in production. Since the departments do not share an overview of these issues with their employees and especially those concerned departments, these issues are now day-to-day occurrences and most departments feel the increased pressure as well as higher stress levels. This in turn causes the problem to continue to worsen: if orders are below average, planners will order nevertheless more (in anticipation of higher orders arriving later), but if they are above average they will mostly still do the same (in order to avoid even higher orders arriving later on). This impulsive behavior in company 2's departments without understanding the huge disadvantages it creates will continue to add to the high employee turnover, the pressure and stress levels felt by some key team leaders, supervisors and managers and will sharpen the issues as the company will continue to be hiring new staff as their plans to extend the manufacturing plant until 2025 are already under way.

4. RESULTS AND RECOMMENDATION

The overall results obtained and presented within the current paper confirm high order variation builds up within the short loop supply chains of the 2 companies. The overall average of company 1's order variation to its suppliers in 25 weeks (32.66%) was above 30%, whereas company 2's same indicator (43.65%) was even higher, being above 40%. Both companies' maximum variation range more than tripled their associated order variations (3.43 for company 1 and 3.52 for company 2).

Company 1's supplier base is more scattered throughout Europe (longer distances as well), but its order variation pattern is fairly sinuous and has a rather constant spread pattern. Average variation of customer orders (5.43%) exceeded the agreed threshold (only 3 suppliers being within the agreed interval), whereas the corresponding variation sent by company 1 towards its suppliers was 6.01 times higher. Company 2' suppliers are denser (half being based in the same country) and overall distances are shorter (1,000 km less), but its order variation pattern is distorted and has a visibly more disrupted spread pattern. Average variation of customer orders (3.98%) is well within the agreed threshold (7 out of 10 suppliers within the agreed interval) with the range being 3 percentage points higher (4.84% compared to 1.82%), while the corresponding variation sent by company 1 towards its suppliers was 10.94 times greater.

Surprisingly, if judging macro data, company 2's measured performance was lower even with shorter distances and better customer order compliance. Despite incurring a lower customer order variation (-26.55%), company 2 generated a higher average order variation (+33.62%) and higher order variation range (+36.76%) than company 1. On a micro level: 22% of working time is spent on recurring issues (repetitive data transfers, escalation procedures and emergency decision-making that occur on a rather regular basis) while a part of performance assessment is based on inaccurate KPIs (automatically calculated, but between one and two thirds contain errors that need to be manually corrected by different data analysts), all of which occurs during a constant rise in volumes of activity. Induction and training for new employees is rather scarce (less time is available to properly perform induction, basic tasks often contain a much higher amount of specific issues, interns usually need to be given hands-on responsibilities despite lack of basic knowledge and/or training) and contributes to accumulating issues, despite reports showing that between 29% and 47% of them could be avoided by taking the time to properly instruct new apprentices.

Within the full reports submitted, medium and long-term recommendations are made that enable a more productive work environment visible after 3 months of applying the set of required actions. The degree of the department's active effort to seek improvements could reduce current issues by up to two thirds (57% for company 1 and 72% for company 2) within a year. A more efficient working environment is essential for company 2 as the manufacturing plant is planned to increase its production activity by 25% until 2025.

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THE INFLUENCE OF THE TRANSPORT PROBLEM ON THE OPTIMIZATION OF THE TRANSPORT NETWORK OF MILITARY LOGISTIC SUPPORT

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Abstract: The role of the modern logistics infrastructure of a military organization is to respond to the challenges of transportation for the purpose of logistical support using the optimization of the transportation network through solving the transportation problem with the ultimate goal of achieving the sustainability of the military organization. The subject of the research in this paper is to define and carry out an analysis of the transport network of a military organization, and based on the obtained results, to determine in what way and by which transport routes there is a significant possibility of reducing costs related exclusively to transport lines of communication and transport costs within the transport network. The goal of the research is to investigate whether there is a possibility and how is it possible to save the resources of the military organization in all segments, which also includes the planning of the transport network of logistical support by solving the transport problems of distribution between barracks and military warehouse complexes (military storage complex - MWC). The results of the research showed that there are transport routes on which there is a significant reduction in costs, which refers exclusively to the routes and transport costs within the transport network.

Keywords: transport network, optimization of the transport network, cost decreasing, software tool, routes, optimal solution

1 INTRODUCTION

The purpose of this research is to define and carry out an analysis of the transport network in the military organization, and based on the obtained results to investigate in what way and by which transport routes there is a significant possibility of reducing costs related exclusively to transport lines of communication and transport costs within the transport network. The aim of this paper is to investigate whether there is a possibility and how it is possible to achieve the saving of resources of the military organization in all segments, which includes the planning of the transport network of logistical support by solving the transport problems of distribution between barracks and military storage complexes (military warehouse complex - MWC). Logistics in a military organization is a functional area in which the logistical functions of the system are organized and developed, and material disposal and provision of logistical support is carried out [1]. Regardless of the fact that logistics is not a single organization, a single logistics process is implemented in all components of the logistics functional area [2]. Movement causes a change in the spatial position of the forces together with their equipment and supplies of material resources necessary for action [3]. Transport support for movement consists of transport, mobility, transport infrastructure and management (planning, implementation, control) of movement [4]. In today's economic environment, where time is money, savings become the key to success. At the same time, when talking about savings in the military organization, a significant emphasis is placed on the transport of logistical material resources, from which the need for its constant optimization clearly emerges. For military logistics in peacetime, and especially in times of war, a key factor is the transport system for moving the forces that need to be deployed on the battlefield and its ability to supply the same forces after they occupy their positions [5]. Military logistics took over the integrated management of military logistical material and technical resources and their physical implementation [6]. The procurement of raw materials for the production of military materials, as well as the procurement of materials and the process of logistical support itself, were one of the crucial novelties of military logistics. Also, logistics engineering began to develop, whose task was to ensure the production of military equipment that was suitable for logistical support covering the entire life span [7]. Military logistics took over the forecasting and planning of needs for all types of logistical support and more important allied NATO logistics issues [8]. It is important to note that civil logistics used American war experiences in supplying the army all over the world, the most significant of which are the use of containers, transport pallets, "overseas" (protective) packaging, etc. [9]. In today's military operations, the transport element of logistics support is the key to logistics operations. A statement by US General Frederick Benjamin "Ben" Hodges III confirms his view of supporting today's military operations: "War is a test of will and logistics." Logistics in a military organization is a functional area in which the construction and functionality of the logistics system and the implementation of material disposal and logistical support takes place [10].

2 MATERIAL AND METHODS

By applying exact methods, it is possible to obtain an optimal solution to the logistics problem, which is described by a mathematical model of the transport problem. A transport problem is a problem in which the transport schedule of a certain transport substrate is determined - homogeneous cargo units such as pallets, boxes and cartons from (n) sources where the substrate is located in (m) destinations whose demand for the substrate needs to be met, using the criteria of the lowest transport costs or the shortest transport time times along the available transport routes. For example, the transport problem can be solved using the graphical method or the simplex method (linear programming), and if the application of these methods would require an unacceptably long time, it can be solved using heuristic algorithms such as ant colony, simulated hardening and others. Such algorithms provide solutions that cannot be considered optimal with certainty, but are applicable with respect to the given constraints [11]. However, as in the specific problem of optimizing the transport network of logistics support, it is necessary to apply current practical knowledge and skills on examples of three basic logistics problems, the optimization of the linear programming mathematical model will be presented using the MS Excel program tool Solver, which is part of the standard MS Office software package. The knowledge and skills acquired through its application can serve as a basis for further study of models and methods of solving logistical problems using more sophisticated software tools. The vast majority of logistics problems that arise in the planning and management of logistics processes can be reduced to optimization problems using transport models. It is through the application of transport models that the functioning of the transport network as a whole can be optimized in this sense [12]. In order to obtain an optimal solution to the transport problem, it is necessary to connect source hubs (military storage complexes) and destination hubs (barracks) with transport routes so that the demand is satisfied and the cost of transport for the military organization is minimal [11],[13],[14],[15],[16],[17]. Here we are talking about problems that have several feasible solutions, from which one should choose the one that gives the best result according to the adopted criteria (or more). Of course, the set limitations must be respected [13].

3 RESULTS

3.1 Input data – example problem

As an example for solving the transport problem in a military organization, we will take the initial elements: from eight military storage complexes (military warehouse complex - MWC) shown in Figure 1, 14 barracks should be supplied with material and technical means (material and technical means - MTS). The geographical distribution of MWC and barracks, as well as road infrastructure, are shown in Figure 1.

Figure 1 Location of MWC and barracks

Other input data, such as mutual distances between MWC and barracks expressed in tons per kilometer (ton kilometer - tkm), MWC demand (expressed in tons) and barracks capacity (expressed in tons), are given in Figure 2.

	Distances (km)													
MWC/Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj
1. Velika Buna	424	249	313	27	38	188	295	238	255	214	521	255	151	120
2. Sv. Rok	192	26	74	229	273	397	63	447	464	32	289	464	360	103
3. Knin	86	88	10	302	346	470	95	520	537	105	192	537	433	166
4. Slunj	289	78	165	107	94	274	160	325	341	94	386	341	237	10
5. Daruvar	535	360	424	129	104	68	406	96	168	325	632	168	32	231
6. Trbounje	77	110	26	363	407	531	93	581	598	127	205	598	494	188
7. Varažd. breg	489	315	378	83	131	230	361	280	297	280	586	297	113	185
8. Križevci	475	300	364	68	117	216	346	170	283	266	572	283	80	171
Requests (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17

Figure 2 Input data for an example of a transportation problem

For a time period of one month, it is necessary to determine an optimal transport schedule, where the demand will be satisfied with minimal operation of the vehicle fleet, respecting the given restrictions: the demand in each barracks must be satisfied, and the maximum total amount of goods that can be delivered from an individual MWC is limited the available quantity of goods in the respective MWC, that is, the capacity, which will be described in the rest of the work. Furthermore, the given problem will be described with the addition of certain conditions in order to see their influence on the optimization of the transport of military storage complexes. Before proceeding with the creation of a mathematical model of this problem, it is necessary to check whether the problem is solvable, as mathematically formulated by expressions (1), (2) and (3).
Let it be:

$$\boldsymbol{K} = \sum_{i=1}^{n} \boldsymbol{k_i} \tag{1}$$

$$\boldsymbol{P} = \sum_{j=1}^{m} \boldsymbol{p_j} \tag{2}$$

Where is:
n = the total number of MWC
k_i = the capacity of MWC at the location i
K = total capacity of all MWC
m = the total number of barracks to be supplied ($m = 14$)
P_j = demand in the barracks j
P = total demand of all barracks

The problem is solvable if:

$$\boldsymbol{K} \geq \boldsymbol{P} \tag{3}$$

3.2 Mathematical model of the problem

The mathematical model of the problem is created on the basis of a logical description of the problem with the use of input data. The objective function is given by expression (4).

$$\min F = \sum_{i=1}^{n}\sum_{j=1}^{m} d_{ij} \cdot q_{ij} \tag{4}$$

With the restrictions (conditions) given by expression (5):

$$\sum_{i=1}^{n} \boldsymbol{q_{ij=}\, p_j} \tag{5}$$

for each j = 1,..., m (satisfied demand in each barracks)

There is no limit to the capacity of MWC.
Where is:

d_{ij} = distance from the MWC i to the barracks j
q_{ij} = decision variable: quantity of goods supplied to barracks j from MWC i
m = the total number of barracks to be supplied ($m = 14$)
n = the total number of MWC ($n = 8$)
k_i = monthly capacity of MWC i
p_j = monthly demand in the barracks j

Each solution (combination of values q_{ij}, $i = 1, ..., n$, $j = 1, ..., m$) that meets the set constraints is a feasible or possible solution, and there are more such solutions. The optimal solution is one of the possible solutions, in this case the one that requires the least work of the vehicle fleet.

3.3 The optimal soution to the Basic transport problem

The optimal solution of the monthly transport schedule that meets the set constraints with the least transport costs obtained by optimizing the mathematical model using the MS Excel program tool Solver tells us the following shown in Figure 3. The MWC in the great Buna supplies barracks Zagreb (40 tons) and Petrinja (12 tons). The total amount of goods transported from this MWC is (52 tons). In Sveti Rok, MWC supplies the barracks in Udbina (10 tons), Gospić with 12 tons, and the barracks in Zemunik with 8 tons of goods per month. The total amount of goods transported by this MWC is 30 tons. MWC in Knin supplies barracks in Knin (13 tons) and Ploče with (7 tons) of goods per month. The total amount of transported goods is 21 tons. MWC in Slunj supplies the barracks in Slunj with (17 tons) of only once a month. MWC in Doljani supplies the barracks in Požega (14), the military training ground in Djakovo with 18 tons, Našice with 50 tons, the barracks in Djakovo with 20 tons of goods, Velika Peratovica with 5 tons of goods. The total amount of transported goods is 107 tons. MWC in Trbounje supplies the barracks in Split with 20 tons. The total amount of transported goods is 20 tons. MWC in Varaždin Breg and MWC in Križevci do not supply any barracks, and therefore 0 tons were delivered from these barracks. A total of 16,820,000 kilometers were traveled by transporting material and technical resources from all MWCs to barracks without the default MWC capacity limit.

	Transporting schedule (t)															
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Transported from MWC (t)	Number of barracks supplied
1. Velika Buna	0	0	0	40	12	0	0	0	0	0	0	0	0	0	52	2
2. Sv. Rok	0	10	0	0	0	0	8	0	0	12	0	0	0	0	30	3
3. Knin	0	0	13	0	0	0	0	0	0	0	7	0	0	0	20	2
4. Slunj		0	0	0	0	0	0	0	0	0	0	0	0	17	17	1
5. Daruvar	0	0	0	0	0	14	0	50	18	0	0	12	5	0	99	5
6. Trbounje	20	0	0	0	0	0	0	0	0	0	0	0	0	0	20	1
7. Varažd. breg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Križevci	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Delivered in MWC/barrack (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17		
In total (thousand kilometers): 16.820																

Figure 3 Optimal schedule of transport from MWC to barracks

To the basic transport problem, the limitation of the capacity of military storage complexes was added, as shown by formulas (6) and (7):

$$\sum_{j=1}^{m} \boldsymbol{q_{ij \le k_i}} \tag{6}$$

for each i = 1,..., n (supply from MWC is limited by its capacity)

The problem is solvable if:

$$K \geq P \tag{7}$$

The total monthly capacity of MWC is K = 1700 tons.
The total monthly demand of all barracks is P = 238 tons.
Since 1700 > 238, the problem is solvable.

Figure 4 shows the optimal solution of the transport problem with MWC capacity limitation. Considering that MWC capacity is significantly higher than the demand of the military, MWC capacity was not used to the maximum even once, which does not bring the problem to a different situation than it was in the first case. The MWC in Varaždin Breg and Križevci do not supply any barracks, while the MWC in Daruvar is closest to its maximum capacity utilization. In the other MWCs, there is still enough capacity to supply the barracks in some emergency cases. The total distance traveled is still 16,820,000 kilometers.

	Distances (km)														
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Capacity of MWC/barrack (t)
1. Velika Buna	424	249	313	27	38	188	295	238	255	214	521	255	151	120	300
2. Sv. Rok	192	26	74	229	273	397	63	447	464	32	289	464	360	103	300
3. Knin	86	88	10	302	346	470	95	520	537	105	192	537	433	166	200
4. Slunj	289	78	165	107	94	274	160	325	341	94	386	341	237	10	100
5. Daruvar	535	360	424	129	104	68	406	96	168	325	632	168	32	231	100
6. Trbounje	77	110	26	363	407	531	93	581	598	127	205	598	494	188	200
7. Varažd. breg	489	315	378	83	131	230	361	280	297	280	586	297	113	185	300
8. Križevci	475	300	364	68	117	216	346	170	283	266	572	283	80	171	200
Requests (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17	

	Transporting schedule (t)															
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Transported from MWC (t)	Number of barracks supplied
1. Velika Buna	0	0	0	40	12	0	0	0	0	0	0	0	0	0	52	2
2. Sv. Rok	0	10	0	0	0	0	8	0	0	12	0	0	0	0	30	3
3. Knin	0	0	13	0	0	0	0	0	0	0	7	0	0	0	20	2
4. Slunj		0	0	0	0	0	0	0	0	0	0	0	0	17	17	1
5. Daruvar	0	0	0	0	0	14	0	50	18	0	0	12	5	0	99	5
6. Trbounje	20	0	0	0	0	0	0	0	0	0	0	0	0	0	20	1
7. Varažd. breg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Križevci	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0
Delivered in MWC/barrack (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17		
In total (thousand kilometers): 16.820																

Figure 4 Optimal solution of the transport model with MWC capacity limitation

The next added condition (limitation) in the optimization of the transport network of military storage complexes MWC will be precisely the transport capacities of individual MWCs. Namely, not every MWC has the same number and type of means of transport, and for this reason it is not possible to transport the same amount of goods. According to the capabilities of each MWC, the optimization in Figure 4 shows how the number of supplied barracks changes. MWC in Velika Buna is now supplying the barracks in Zagreb with 25 tons of goods, and the barracks in Petrinja with 12 tons of material and technical resources due to limited transport capacities. It also supplies the barracks in Našice with 10 tons of goods. With its capacities, it supplies a total of 3 barracks. The MWC in Sveti Rok supplies the barracks in Udbina with 10 tons, Zemunik with 8 tons, and the barracks in Gospić with 12 tons of consumables. In total, it supplies 3 barracks. MWC in Knin supplies the barracks in Knin with 10 tons, and the barracks in Ploče with 7 tons of consumables. The total amount of transported goods is 17 tons in two barracks. MWC in Slunj supplies the barracks in Slunj with 17 tons of goods per month. MWC in Doljani supplies the barracks in Požega with 14 tons, the military training ground in Djakovo with 18 tons, Nasice with 25 tons, the barracks in Djakovo with 12 tons, Velika Peratovica with 5 tons of goods. The total amount of transported goods is 74 tons in 5 barracks. MWC in Trbounje transports 20 tons of consumables to the barracks in Split and Knin (3 tons). MWC in Križevci supplies barracks in Zagreb and Našice with 15 tons of goods each. The MWC in Varaždin Breg does not supply any barracks.

	Distances (km)															
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Capacity of MWC/barrack (t)	Transport capacity (t)
1. Velika Buna	424	249	313	27	38	188	295	238	255	214	521	255	151	120	300	25
2. Sv. Rok	192	26	74	229	273	397	63	447	464	32	289	464	360	103	300	15
3. Knin	86	88	10	302	346	470	95	520	537	105	192	537	433	166	200	10
4. Slunj	289	78	165	107	94	274	160	325	341	94	386	341	237	10	100	5
5. Daruvar	535	360	424	129	104	68	406	96	168	325	632	168	32	231	100	25
6. Trbounje	77	110	26	363	407	531	93	581	598	127	205	598	494	188	200	10
7. Varažd. breg	489	315	378	83	131	230	361	280	297	280	586	297	113	185	300	20
8. Križevci	475	300	364	68	117	216	346	170	283	266	572	283	80	171	200	15
Requests (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17		

	Transporting schedule (t)															
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Transported from MWC (t)	Number of barracks supplied
1. Velika Buna	0	0	0	**25**	**12**	0	0	**10**	0	0	0	0	0	0	47	3
2. Sv. Rok	0	**10**	0	0	0	0	**8**	0	0	**12**	0	0	0	0	30	3
3. Knin	0	0	**10**	0	0	0	0	0	0	0	**7**	0	0	0	17	2
4. Slunj		0	0	0	0	0	0	0	0	0	0	0	0	**17**	17	1
5. Daruvar	0	0	0	0	0	**14**	0	**25**	**18**	0	0	**12**	**5**	0	74	5
6. Trbounje	**20**	0	**3**	0	0	0	0	0	0	0	0	0	0	0	23	2
7. Varažd. breg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Križevci	0	0	0	**15**	0	0	0	**15**		0	0	0	0	0	30	2
Delivered in MWC/barrack (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17		
In total (thousand kilometers): 20.013																

Figure 5 Optimization of the transport problem with limited transport capacities

The total minimum monthly transport cost at the level of the entire transport network amounts to €127,400 shown in Figure 6. When creating the optimization of transport costs, the values of the amount from the transport department of the military organization [18] were taken, where it is €664 for a distance of up to 100 kilometers; €800 for distances of 100 to 200 kilometers; €1,060 for a distance of 200 to 300 kilometers transporting 40 tons of goods, and correspondingly adjusted prices for other distances. The optimization of transport costs includes transport by a vehicle with a load capacity of up to 5 tons, which the military organization has in its possession at its disposal.

	Distances (km)															
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Capacity of MWC/barrack (t)	Transport capacity (t)
1. Velika Buna	424	249	313	27	38	188	295	238	255	214	521	255	151	120	300	25
2. Sv. Rok	192	26	74	229	273	397	63	447	464	32	289	464	360	103	300	15
3. Knin	86	88	10	302	346	470	95	520	537	105	192	537	433	166	200	10
4. Slunj	289	78	165	107	94	274	160	325	341	94	386	341	237	10	100	5
5. Daruvar	535	360	424	129	104	68	406	96	168	325	632	168	32	231	100	25
6. Trbounje	77	110	26	363	407	531	93	581	598	127	205	598	494	188	200	10
7. Varažd. breg	489	315	378	83	131	230	361	280	297	280	586	297	113	185	300	20
8. Križevci	475	300	364	68	117	216	346	170	283	266	572	283	80	171	200	15
Requests (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17		

	Transporting schedule (t)															
MWC / Barrack	1. Split	2. Udbina	3. Knin	4. Zagreb	5. Petrinja	6. Požega	7. Zemunik	8. Našice	9. Đakovo	10. Gospić	11. Ploče	12. Đakovo	13. V.Perat.	14. Slunj	Transported from MWC (t)	Number of barracks supplied
1. Velika Buna	0	0	0	**25**	**12**	0	0	**10**	0	0	0	0	0	0	47	3
2. Sv. Rok	0	**10**	0	0	0	0	**8**	0	0	**12**	0	0	0	0	30	3
3. Knin	0	0	**10**	0	0	0	0	0	0	0	**7**	0	0	0	17	2
4. Slunj		0	0	0	0	0	0	0	0	0	0	0	0	**17**	17	1
5. Daruvar	0	0	0	0	0	**14**	0	**25**	**18**	0	0	**12**	**5**	0	59	5
6. Trbounje	**20**	0	**3**	0	0	0	0	0	0	0	0	0	0	0	23	2
7. Varažd. breg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Križevci	0	0	0	**15**	0	0	0	**15**	0	0	0	0	0	0	45	2
Delivered in MWC/barrack (t)	20	10	13	40	12	14	8	50	18	12	7	12	5	17		
Cost in total (€): 127.400€																

Figure 6 Minimum total monthly transport cost

The graphic representation of the obtained optimal solution of the transport schedule is shown in Figure 7. The arrows represent the connections between the source (MWC) and the destination (barracks), where the arrows do not show the actual transport routes, but only a virtual representation of the connection of the source and destination for the transport of military supplies. It takes place along road routes that connect the MWC and a certain barracks.

Figure 7 Graphic representation of the optimal solution to the transportation problem

4 DISCUSSION

Since transportation costs can amount to up to 50% of total logistics costs, it is logical that improving transportation efficiency has a significant impact on increasing the overall performance of the logistics network. For the aforementioned reasons and the importance of transport in logistics, transport is always considered seriously and for this reason there are a number of mathematical methods that deal exclusively with the transport problem and the problem of directing transport vehicles. Although even modern mathematical methods still do not enable the calculation of optimal solutions to extremely complex logistics problems, and this is their major drawback, they are still used and improved on a daily basis. In addition, problems arise even with their application in solving transport problems for the reason that they require adequate professional knowledge and skills about modern technologies and scientific research methodologies, which means that they can only be used successfully, efficiently and rationally by professionally competent experts. In particular, mathematical methods can be implemented in programming tools and thus enable experimentation with planned ideas, in a relatively more profitable way and without unwanted consequences. It is a quick and simple way of reaching the expected results, which can later be easily checked and evaluated, and based on this, conclusions can be drawn about whether something is effective and profitable for application in the real world. Undoubtedly, in the near future, artificial intelligence AI will play a major role in the planning of military operations, as well as in solving such transport problems, reducing costs and increasing overall efficiency. It will certainly reshape the overall planning and management of both military and civilian traffic.

5 CONCLUSION

Mathematical methods and software tools based on them are used to solve the transport problem through optimization, which primarily aims to minimize costs. Any organization that tends to improve its efficiency, and consequently expects to improve some crucial issues related to the logistics processes of transporting material and technical resources, will primarily work on optimization. Consequently, positive effects can also be observed through a better design of the transport network and an improved schedule of goods transport, which does not mean that the working abilities of network users will decrease, but quite the opposite, it happens that their degree of utilization increases with a significant reduction in "empty kilometers".

We can conclude that the results obtained in this work provide optimal solutions aimed at a better service of lowering transport costs, which the military organization always strives for, with an emphasis on price. From the above, it can be concluded that transport plays a very important role in logistics processes. Guided precisely by this and the aforementioned possibilities provided by mathematical methods, this paper examined the profitability of optimizing the logistics support transport network, and the results are more than satisfactory. Based on the collected and analyzed data, the obtained results in all segments surpass the existing state of the transport network. Ultimately, this was exactly the aim of this paper, to optimize the transport network of logistic support on a real example using mathematical methods and software tools. Professional personnel in the hierarchical structure of the military organization are responsible for the final appearance of the logistics support transport network.

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