Transporta un sakaru institūts
Transport and Telecommunication Institute

RESEARCH and TECHNOLOGY – STEP into the FUTURE

Volume 13. No. 2 - 2018

Special Issue
Sci-Bi: Digitalization in Logistics and Transport

ISSN 1691-2853
ISSN 1691-2861
(On-line: www.tsi.lv)

Riga
2018

Supporting Organization:

Latvian Transport Development and Education Association
Latvian Operations Research Society

THE JOURNAL IS DESIGNED FOR PUBLISHING PAPERS CONCERNING THE FOLLOWING FIELDS OF RESEARCH:

- mathematical and computer modelling
- mathematical methods in natural and engineering sciences
- computer sciences
- aviation and aerospace technologies
- electronics and telecommunication
- telematics and information technologies
- transport and logistics
- economics and management
- social sciences

Articles and review are presented in the journal in English, Russian and Latvian (at the option of authors).
This volume is published without publisher editing.

EDITORIAL CORRESPONDENCE

Transporta un sakaru institūts (Transport and Telecommunication Institute)
Lomonosov 1, LV-1019, Riga, Latvia. Phone: (+371)67100594. Fax: (+371)67100535
E-mail: junior@tsi.lv, http:// www.tsi.lv

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No 2

ISSN 1691-2853, ISSN 1691-2861 (on-line: www.tsi.lv)

The journal of Transport and Telecommunication Institute (Riga, Latvia)
The journal is being published since 2006

SCI-BI: Digitalization in Logistics and Transport

The project of Baltic-German University Liaison Office is supported by the German Academic Exchange Service (DAAD) with funds from the Foreign Office of the Federal Republic Germany.

The aim of the project is strengthening the research capacity of Latvia in Digitalization in Logistics and Transport and stimulating synergies between research and business in Baltic. The project will increase ensuring better compliance of the research achievements with the labour market needs, anticipated to enhance the Baltic institutions' S&T capacity and the quality and quantity of new business deal flow in the region and to accelerate growth and fully In line with the Union's Regulation 1301/2013 and Latvian National Development Plan (2030). One lever is the sensitization of doctorates for such societal tasks, who´s responsibility it is to contribute to the advancement of science. There is a need for greater research understanding of the open questions in transport and logistics associated with implementing digital technologies.

Partners involved in the project:

- Transport and Telecommunication Institute (TTI, Latvia) – leading partner.
- Otto von Guericke University Magdeburg, Institute of Logistics and Material Handling Systems (ILM, Germany).
- Fraunhofer Institute for Factory Operation and Automation (IFF, Germany).
- Vilnius Gediminas Technical University (VGTU, Lithuania).
- Tallinn University of Technology (TTU, Estonia).
- RISEBA University of Business, Arts and Technology (RISEBA, Latvia).

Expected impacts of the project:

- Improved/wider professional relevance of PhD degrees
- Higher quality and quantity of knowledge-intensive innovations
- More effective usage of science in business
- To build a strong link between world class innovative research and creation of high-growth knowledge-based businesses (Lisbon agenda)
- To increase the quality and quantity of new business deal flow in the region and to accelerate growth
- Improving international collaboration in research in indicated area
- The societal impact of PhD research becomes more visible.

Main activities of the project

1. Open Workshop "Digitalization in Logistics and Transport" in Riga, TTI (26.04.2018).
2. Preparation of the International Innovative PhD seminar.
3. Participation in International Doctoral Student Workshop in Magdeburg, 19.06.2018.
4. International Innovative PhD seminar "Sci-Bi: Digitalization in Logistics and Transport"(Riga, TTI), 16.10.2018 where PhD and Msc students presented their research into the following topics:
   a. Smart Solutions in Logistics and Transport
   b. Decision-making on the basis of Modelling and Simulation
   c. Impacts on Economics and Society
5. Issue of Journal "Research and Technologies - Step to the Future" with papers that presented at PhD seminar "Sci-Bi: Digitalization in Logistics and Transport".

http://www.tsi.lv/en/content/sci-bi-digitalization-logistics-and-transport

This project of the Baltic-German University Liaison Office is supported by the German Academic Exchange Service (DAAD) with funds from the Foreign Office of the Federal Republic Germany.

Transport and Telecommunication Institute

The Transport and Telecommunication Institute (TTI) is the largest university-type accredited non-state technical higher educational and scientific establishment in Latvia. It was established in 1999 and is situated in Riga. Currently about 3000 students are enrolled in B.Sc., M.Sc. and Ph.D. programmes and provides with the academic programs in the following directions: transport and logistics, computer sciences, electronics and telecommunication, economics and management, aviation transport.

TSI is conducting the diversified research scientific work. According to the results of expert evaluation Transport and Telecommunication Institute is the only one among private colleges included in the list of leading scientific institutions, acting in Latvia. The Transport and Telecommunication Institute has its main research activities in:

1. ICT (Telematics)
2. Smart Solutions in Transport and Logistics
3. Digital Society and Economy

TTI has a positive experience in providing consulting service to the business and industry entities. For the last 6 years TTI has implemented more than 10 consulting projects for business and municipal organizations.

The TTI Research Infrastructure includes:

1. Laboratory of Applied Software Systems (LAS). LAS carries on research and offers consulting in the following fields: traffic, logistics and business processes using nowadays simulation software for the high-quality, representative and many-sided analysis of the complex systems. In LAS portfolio - the projects connected with the new bus station in Riga, three level trestle of South bridge model, Liepaja city traffic macroscopic model, RIX airport terminal model etc.

2. Telecommunications, electronics and robotics center (TERC). The center was founded in 2013 and includes nine laboratories equipped with the latest software and hardware widely used in academic and research activities. Each laboratory is a collection of contemporary technical, software and methodological maintenance, which allows conducting classes with students and providing researches at the highest level.

   The following laboratories were formed and equipped as part of the center:
   Laboratory of Modelling of Electronic Systems
   Laboratory of Embedded Systems and Digital Signal Processing
   Laboratory of Industrial Automation
   Laboratory of Subsurface Radiolocation
   Laboratory of Robotics and Students' Research Work
   Laboratory of Designing And Prototyping
   Laboratory of Telecommunications and Electro-Optical Systems
   Laboratory of Electronics
   Laboratory of Physics and Electrical Machines.

www.tsi.lv

Fraunhofer Institute for Factory Operation and Automation

The Fraunhofer Institute for Factory Operation and Automation IFF uses custom solutions to help German and foreign companies make their manufacturing smarter. Fraunhofer IFF is a technology partner specialized in planning, developing, equipping and operating work, manufacturing and supply chain systems as well as their supply infrastructures. They design work systems in which humans and machines collaborate side-by-side. They combine these work systems in efficient manufacturing and supply chain systems and use smart infrastructures to connect them with each other and their environment.

Digital engineering integrated throughout product and manufacturing system life cycles is crucial. Fraunhofer IFF achieves this with interoperable methods and tools as well as our expertise in robotics, testing and inspection systems, technology-based assistance and learning systems, and manufacturing and supply chain process engineering.

As a technology partner to companies, they research, develop and improve technologies, systems and products from the idea to manufacturability – and implement them in companies in short time, combining their industry experience and research expertise to do so.

Fraunhofer IFF thus empowers companies to operate adaptively in the marketplace and to boost their manufacturing's performance and reliability. This means that Fraunhofer IFF makes workplaces smarter so that they assist workers according to their skills and maintain the quality of products and processes. They organize manufacturing and supply chains to be more energy and resource efficient. They consolidate regional energy, information and communications networks to make supply smart and reliable.

www.iff.fraunhofer.de

Otto Von Guericke University Magdeburg

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

Consisting of 9 Faculties, OvGU offers more than 70 academic programs. Nearly 14,200 students are enrolled at OvGU; 2,400 of them are international students. OvGU is one of Germany's youngest universities. Its innovative fundamental research contributes to the city's and the country's social and scientific development.

The Institute of Logistics and Material Handling Systems is part of the Faculty of Mechanical Engineering and looks back on more than 50 years of experience in training and research in the field of conveying technologies, logistics and material handling systems.

The fields of research include:

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

www.ilm.ovgu.de

Vilnius Gediminas Technical University

Vilnius Gediminas Technical University (VGTU) is one of the largest Lithuanian higher education institutions, the leader in technology sciences. There are 10 faculties including Antanas Gustaitis Aviation Institute, Architecture, Business Management, Civil Engineering, Creative Industries, Electronics, Environmental Engineering, Fundamental Sciences, Mechanics, Transport Engineering. Scientific research and experimental development are performed by 13 institutes, 3 research centers and 23 research laboratories.

International Recognition:

- VGTU is ranked 41st in the Emerging Europe and Central Asia region according to the “QS World University Rankings” and is the leading technical university in Lithuania.
- VGTU is the best Baltic university in the subject area of Civil Engineering and Building Construction (QS Top 101–150) according to the “QS World University Rankings by Subject”.
- VGTU is the best university in Lithuania in the subject areas of Architecture (QS Top 101–150), Business and Management (QS Top 201–250) and Economics and Econometrics (QS Top 201–250) according to the “QS World University Rankings by Subject”.

Studies:

Over 100 study programmes including 51 Bachelor’s; 55 Master’s and 3 integrated study programmes. Over 50% of study programmes are interdisciplinary. Study programmes in the field of engineering sciences make 60% of all study programmes offered by the University.

International students at VGTU:

- Over 10% of all VGTU students are international (degree seeking or exchange) all over the world (more than 80 countries)
- Every 7th VGTU student goes abroad for long-term study or internship mobility
- VGTU has the highest the number of international degrees seeking students in Lithuania. Most degree seeking students come from India, Turkey, Belarus and Ukraine. Most exchange students come from partner universities in Spain, France, Germany and Turkey.

Partnerships:

- Partner universities in 67 countries: 28 in Europe, 39 outside Europe
- 30 Bachelor’s and Master’s programmes are taught in English
- 8 joint or double degree programmes with universities abroad
- 40 international research and study projects

Research priorities:

- Sustainable transport
- Sustainable building
- Environmental and energy technologies
- Mechatronics
- Information and communication technologies
- Economics engineering, management and communication
- Fundamental research on materials and processes

https://www.vgtu.lt

"RISEBA" University of Business, Arts and Technology

"RISEBA" University of Business, Arts and Technology is a university type private higher educational institution fully accredited by the Ministry of Education and Science of the Republic of Latvia.

Being one of the first private higher education institutions in Latvia, today RISEBA is among 10 largest higher education institutions in Latvia (both public and private) with almost 3000 students, including 200 international students, who attend 20 study programmes of different levels and directions, and more than 12 000 alumni.

Over the last two decades, RISEBA has gone through a substantial transformation from a small ambitious business school to the university that provides, in addition to business and management programmes, studies in communications, audiovisual media arts and architecture, thus transforming the institution into “the place where business meets art”.

RISEBA stands out from the other higher education institutions as the one having clear international focus and is distinguished by the exclusivity of the study programmes offered and variety of languages of instruction.

RISEBA provides programmes which are either unique in the market or were first introduced to the market by RISEBA. It is one of the few institutions that offer full degree programmes in three languages – Latvian, English and Russian.

RISEBA is spread across five sites: three buildings of RISEBA main campus are located in Riga (the capital city), one regional branch is based in Daugavpils (the second largest city in Latvia).

Guided by its vision RISEBA comprises three major academic components or schools:

School of Business with Bachelor, Master and PhD programmes, which cover the areas of business, management and economics

School of Media and Communication with Bachelor and Master programmes in arts and communications

School of Architecture and Design, which currently offers an Undergraduate programme and Postgraduate programme in Architecture.

RISEBA is an inter-disciplinary, multicultural university providing the global labour market with intelligent, creative and independent thinking individuals. RISEBA stands for excellent education, internationally recognised degrees, high quality of graduates, excellent research base and highly qualified staff.

RISEBA is the only higher education establishment in Baltics that has been accredited by both EFMD and EPAS.

www.riseba.lv

Tallinn University of Technology

Internationally successful university

TalTech University, the only technological university in Estonia, is the flagship of Estonian engineering and technology education. Here the synergy between different fields (technological, natural, exact, economic and health sciences) is created and new ideas are born. TalTech is to become one of the leading technological universities in the Baltic Sea region.

High-quality programs and successful alumni

Study and teaching is based on internationally recognized research and the graduates are highly rated on the labour market. The University’s approximately 70,000 alumni have shaped the economic landscape of present-day Estonia.

Excellence in research and innovation

TalTech is a university, which by relying on academic competencies and professional management, responds actively to the needs of the rapidly developing society and is involved in tackling the challenges of the digital era.

Inspiring environment

TalTech offers its students exciting student and cultural life and the best accommodation and sporting opportunities in the Baltic Sea region. The TalTech campus is also a home to more than 200 high-tech companies (e.g. Skype).

Creating the future

TalTech is in charge of nurturing the next generation of engineers and advancing engineering culture in Estonia, contributing to the sustainable development of the society and increased national prosperity with its innovative services. Our vision is innovative Estonia in a sustainable world

www.ttu.ee/en

PhD seminar

"Sci-Bi: Digitalization in Logistics and Transport"

16 October 2018, 9:30-16:30

Venue: Transport and Telecommunication Institute

130 aud., Lomonosov street 1, Riga, Latvia

Moderator: TTI Vice-Rector, Prof. Irina Yatskiv (Latvia)

AGENDA

9:30 Welcome Coffee and registration	
10:00 Photo and Welcoming Remarks	**Prof. Dr.sc.ing. Irina Yatskiv** *Vice-Rector for Research and Development, TTI*
Section 1 (10:15 – 11:15)	
Introductory Speech **How (not) to write a PhD Thesis: A report on my experience**	***Dr.-Ing.Tobias Reggelin*** *Otto von Guericke University Magdeburg, Institute of Logistics and Material Handling Systems (ILM), Germany*
Possible effects of connected and automated driving on the economy, employment and skills: Open Research Questions	**Prof. Dr.sc.ing. Irina Yatskiv** *Vice-Rector for Research and Development, TTI, Latvia*
Applying methods of artificial Intelligence for optimization in production and logistics	**M.Sc. Sebastian Lang** *Otto von Guericke University Magdeburg, Institute of Logistics and Material Handling Systems (ILM), Germany*
Discussion and Wrap-Up	
11:15 -11:30 ***Coffee break***	
Section 2 (11:30 – 12:30)	
Feasible path planning algorithm for city road network	**M.Sc. Paulius Skačkauskas** *Vilnius Gediminas Technical University, Lithuania*
Simulation-driven artificial intelligence for solving stochastic combinatorial optimization problems in production and logistics	**M.Sc. Ilya Jackson** *Transport and Telecommunication Institute, Latvia*
An outlook for the use of cobots in Latvia	**Andris Spulis** *"RISEBA" University of Business, Arts and Technology, Latvia*
Discussion and Wrap-Up	
12:30 – 13:30 ***Lunch break***	

Section 3 (13:30 – 14:30)	
Multi-Layered approach to the UAV collision avoidance system	**M.Sc. Dmitry Lancovs** *Transport and Telecommunication Institute, Latvia*
Smart warehouse concept and underlying technologies: state-of-the-art	**M.Sc. Aleksandrs Avdeikins** *Transport and Telecommunication Institute, Latvia*
Spatial planning scales in urban logistics	**M.Sc. Tom Assmann** *Fraunhofer Institute for Factory Operation and Automation IFF, Germany*
Discussion and Wrap-Up	
14:30 -14:45 Coffee break	
Section 4 (14:45 – 15:45)	
3D-Reconsctruction of human's face in person's identification problem from video stream data	**Fyodor Panchuk** *Transport and Telecommunication Institute, Latvia*
An investigation of alternative methods for controlling the movement of ground vehicles in airports	**Iyad Alomar** *Transport and Telecommunication Institute, Latvia*
Evaluation of the impact of the number of picking locations on the total cost of warehouse	**Raitis Apsalons** *Transport and Telecommunication Institute, Latvia*
Discussion and Wrap-Up	
15:45 Concluding Remarks	
16:00 Get together	

a. Smart Solutions in Logistics and Transport
b. Decision-making on the basis of Modelling and Simulation
c. Impacts on Economics and Society

CONTENTS

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 12-20
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

FEASIBLE PATH PLANNING ALGORITHM FOR CITY ROAD NETWORK

Paulius Skačkauskas, Edgar Sokolovskij

Vilnius Gediminas Technical University
J. Basanavičiaus g. 28, 03224 Vilnius, Lithuania
{paulius.skackauskas,edgar.sokolovskij}@vgtu.lt

Because of the huge interest from the researchers and the industry, autonomous vehicles have become one of the most advancing research fields. Respectively, the future of autonomous vehicles, i.e., the realization of the envisaged benefits, such as increased driving safety or improved transportation efficiency and public acceptance, will depend on their ability to safely move in real road networks and various traffic scenarios. Due to this reason, this paper presents an effective path planning algorithm to generate a feasible and safe path in a city road network. The proposed algorithm is based on the Dubins path approach, a network map of a selected road and a set of waypoints, which represent intersections and their geometry. In order to ensure path feasibility and safety in a city road network, an objective function with inequality constraints is proposed. The performance of the proposed algorithm was demonstrated while applying the algorithm to different road networks of a selected city. The feasibility of the planned path was proven by executing experimental drives with an autonomous test vehicle in an enclosed lot, while imitating the moving in a city road network.

Keywords: Autonomous ground vehicle, Path planning, Dubins path, Optimisation, City road network.

1 Introduction and Literature Review

Increasingly growing support for innovative solutions and deployment of technological innovations in transport systems are two of the main reasons why autonomous ground vehicles (AGVs) are gaining huge interest between the society, industry and the researchers. The AGVs are envisaged to be the sustainable future for enhanced road safety, efficient traffic flow and decreased fuel consumption (Katrakazas *et al*., 2015). Seeking to achieve that the AGVs would be fully valued road users, capability of autonomous driving in real traffic scenarios must be ensured. According to (Katrakazas *et al*., 2015), critical decision making is the key to autonomy and is realised through planning algorithms, incorporated within the middleware of an autonomous vehicle's navigation, situation understanding and decision making module. In this section, a brief review on various on-road path and trajectory planning algorithms is presented.
In general case, path and trajectory planning algorithms, based on their application, can be classified as: algorithms for structured (on-road) environments, like cities, and algorithms for unstructured (off-road) environments, where no road discipline needs to be followed (Katrakazas *et al*., 2015; Chu *et al.*, 2015; Kala, 2016). A critical review on different on-road trajectory planning approaches is given in (Katrakazas *et al*., 2015). Authors in (Katrakazas *et al*., 2015) state that the main purpose of planning is to provide the vehicle with a safe and collision-free path towards its destination, while taking into account the vehicle dynamics, its manoeuvre capabilities, road boundaries, i.e., to provide a feasible path / trajectory. Seeking to ensure trajectory feasibility for autonomous on-road driving, especially on highways, in (Gu and Dolan, 2012) authors provided a two-step method which first finds a coarse trajectory solution and then, based on the "generate-and-test" approach, selects the best feasible and smooth trajectory. A simulation showed that the provided method can robustly handle different dynamic on-road driving scenarios. A similar method, which consists of two stages: global and local planning, for trajectory generation along the route is proposed in (Alcala *et al*., 2018). The

global planner defines the route composed with a set of waypoints along the road. The local planner – a quintic spline-based trajectory planner, which generates a smooth trajectory with a velocity profile with continuous acceleration and low levels of jerk, ensuring the passenger comfort. In the global planner, to introduce the route as a set of waypoints along the road, *OpenStreetMap* open software was used. A dynamic path planning method for autonomous driving on various roads is proposed in (Hu *et al*., 2018). In the proposed method, to select an optimal path, an objective function that considers safety, comfortability, and dynamic costs is designed and used. However, in (Hu *et al*., 2018), as well as in (Gu and Dolan, 2012), the performance of the provided methods was investigated only by a simulation and not with a real autonomous test vehicle. A geometric representation of the feasible path planning algorithm for on-road environments is developed in (Bae *et al*., 2013). The developed algorithm is based on Bezier curves and a kinematic bicycle AGV model. It is stated that the Bezier curve provides a viable way to generate a smooth path between the initial position and the destination. A trajectory generation method, also based on the Bezier curve, for autonomous vehicles in a structured on-road environment, is proposed in (Park *et al*., 2014). The proposed method generates a smooth trajectory using Bezier spiral smoothing, based on the centreline model of a desired lane. A trajectory planning method based on nonlinear optimisation that is able to generate a dynamically feasible, comfortable and customizable trajectory for road vehicles is presented in (Hegedus *et al*., 2017). The main drawback of the presented method – due to the computational effort, the method is not suitable for real-time application. A path planning algorithm that is responsible for safe autonomous driving in structured environments is described in (Kim *et al*., 2013). In order to derive the optimal path, the path planner generates an optimal path based on the road map and perception information. A trajectory planning approach for autonomous vehicles on structured road maps is also proposed in (Boroujeni *et al*., 2017). To generate a safe optimal trajectory, an A-star optimal path planning algorithm was used. In (Gu *et al*., 2013) authors developed a novel, two-step method addressing on-road path planning, which: 1. generates a human-like reference trajectory accounting for road geometry, obstacles and highway directives, 2. evaluates and selects parametric trajectories that further satisfy the used constraints. Authors state that, for future development of the proposed method, the computation speed must be increased. A trajectory planning method that uses triple segments for general posture-to-posture trajectory planning is designed in (Takano *et al*., 2017). Although the computational complexity and computational effort are notable, authors state that the proposed method has reached a basic level for practical use. Authors in (Li *et al*., 2017a) solved the global path optimisation problem in structured environments by performing data acquisition and curvature calculation, while initialising the straights of the reference path and using path primitives to connect the turns between the straights. In (Li *et al*., 2017b), the same authors improved their method and proposed a local path planner for the AGVs driving in structured environments. The improved method avoids solving the nonlinear equations, thus the real-time performance of the method was improved. From the literature review it can be seen that there is a variety of path and trajectory planning algorithms that can be optimisation, graph search, sampling, etc., based, however, all methods have some sort of limitations. In (Kikutis, 2018), it is also pointed out that complex methods and additional computations do not always ensure better path feasibility and accuracy, that is why the development of effective path planning algorithms for a practical application is a relevant task. Due to these reasons, the aim of this work is to develop a global path planning algorithm which will ensure path feasibility in a city road network.

The remainder of this work is organised as follows. In section II the proposed algorithm is introduced. Section III shows the theoretical and experimental application of the proposed algorithm. Final section presents the conclusions of the work.

2 Path Planning Algorithm

In the proposed algorithm it is assumed that there are two sets of waypoints. The first set of waypoints (w_i) defines intersections between different streets and forms a primary coarse path made of straight line segments for the AGV to follow. The second set of waypoints (d_i) defines road network geometry. To introduce a path as two sets of waypoints along the road, a satellite city map is used. In order to ensure smoothness and feasibility of the primary coarse path, two-step optimisation is performed. Firstly, filleted arcs near the intersection waypoints must be inserted. To solve this problem, in this work, the Dubins path approach, which is proposed in (Kikutis, 2018), is used. However, as described in (Kikutis, 2018), the Dubins path approach is based on the assumption that a vehicle always has a minimum tuning radius. Such assumption is not valid in real life scenarios when the vehicle movement is limited by a city road network. Thus, in the second step, an optimisation problem is being solved. To ensure feasibility of the primary path in a city road network, an objective function (Eq. 1) with inequality constraints (Eq. 2 and Eq. 3) is proposed. To evaluate nonholonomic constraints of the AGV, both the objective function and the inequality constraints are based on the kinematic vehicle model, which is described in (Bayar *et al.*, 2016). The proposed objective function, to optimise turning radius:

$$\min f = \sum(x - x_r)^2 + \sum(y - y_r)^2 + \sum\left(\left(\frac{v \cdot \tan^{-1}\left(\tan^{-1}\left(\frac{L}{r}\right)\right) \cdot t}{\sqrt{1+\frac{l_r^2 \cdot \tan\left(\tan^{-1}\left(\frac{L}{r}\right)\right)}{L}}}\right) + \theta_{i-1} - \theta_r\right)^2, \tag{1}$$

where x and y are the position coordinates of the centre of mass of AGV, x_r and y_r are the reference coordinates of the primary coarse path, θ_r is the reference AGV orientation with respect to the fixed frame of the Cartesian coordinates, v is the reference velocity of the AGV while entering into an intersection, L is the AGV wheelbase, r is the optimised turning radius, t is the reference moving time from one transition point to the next transition point of the movement, l_r is the distance from the centre of mass to the rear axle, θ_{i-1} is the AGV orientation at the previous transition point.

It must be noted that in Eq. 1, the given objective function was developed in another work by authors and was used with different inequality constraints for path optimisation in unstructured environments. Based on the structure of the objective function, it can be stated that the developed objective function can be used for both path planning problems, i.e. in structured and unstructured environments. Thus, in this case, the main difference, while solving the optimisation problem of path planning in structured environments, is the development of inequality constraints. New inequality constraints, which consider a second set of waypoints, i.e. the road network geometry and the AGV manoeuvre capabilities, are proposed:

$$r - \left(I + \frac{\tan^{-1} \cdot v \cdot S_R}{\omega}\right) \le 0, \tag{2}$$

where I is the distance between the first and the second set waypoints at the intersection, S_R is the steering ratio of the AGV; ω is the angular velocity of the steering wheel turning.

Taking into account that, in a city road network, intersections can be respectively near to each other, to avoid a turn in the path which may compromise the integrity of the AGV, a second inequality constraint is proposed:

$$r_{i-1} + r_i - w_d \le 0, \tag{3}$$

where r_{i-1} is the turning radius at the previous intersection, r_i is the optimised turning radius, w_d is the distance between waypoints, which mark the intersections.

In Eq. 3 the given inequality constraint ensures better possibilities of the algorithm application in various city road networks. For example, if Eq. 3 is equal to zero, also r_{i-1} and r_i directions are the countercurrent, then the AGV turning manoeuvre is performed. If Eq. 3 is not equal to zero, then there is a straight-line segment between the turning manoeuvres, etc. However, if the path is made from only one intersection and the length of the straight-line segment after the turning manoeuvre is not defined, then the use of Eq. 3 is not needed.

3 Application of the Algorithm

To perform a theoretical and a practical application of the proposed algorithm, the algorithm was designed in *MATLAB / Simulink* software package. While performing the practical application of the proposed algorithm, to implement a basic level of vehicle autonomy, an automated steering device developed by authors, with an *Arduino* microcontroller, mounted on the autonomous test vehicle (Fig. 4), was used. Using the universal asynchronous receiver-transmitter (UART) based communication system, the algorithm was connected in real time with the *Arduino* microcontroller of the automated steering device.

3.1 Theoretical Application of the Algorithm

The theoretical application of the proposed algorithm was performed by selecting two different intersections in Vilnius city, Lithuania. Different scenarios were selected: turning to the right and turning to the left. To illustrate the relation between the AGV velocity during entering the intersection, the angular velocity of the steering wheel turning and the road network (intersection) geometry during path planning, different entering into intersection velocity values and the angular velocity of the steering wheel turning values were selected. The selected values of the velocity during entering the intersection: 3 m/s and 9 m/s. The selected angular constant velocity of the steering wheel turning values: 1.5 rad/s and 2.5 rad/s. The selected scenarios with the marked waypoints and the algorithm application results are given in Fig. 1, Fig. 2 and Fig. 3.

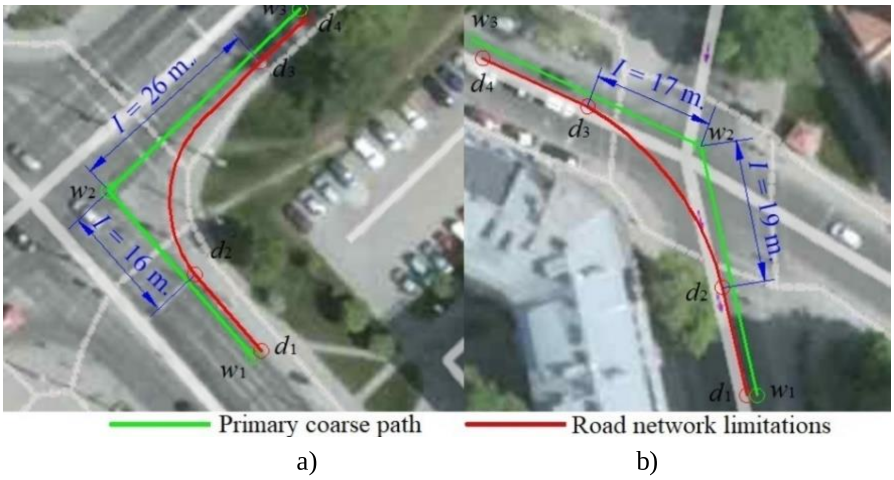


Figure 1. Scenarios for the algorithm application: a – turning to the right, the intersection between Žemaitės and Savanorių streets; b – turning to the left, the intersection between J. Basanavičiaus and Algirdo streets. (Source: by the authors)

From Fig. 1 it can be seen that, due to the intersections geometries, in both scenarios there are two possible different distances *I* between the first and the second set waypoints. In the turning to the right scenario *I* can be 16 and 26 meters (Fig. 1, part a), in turning to the left scenario *I* can be 17 and 19 meters (Fig. 1, part b). To clearly describe the essence of the proposed inequality constraints, it should be pointed out that, in order to increase path feasibility, in the proposed first inequality constraint (Eq. 2) it is assumed that if, due to the intersection geometry, different distances I between the first and the second set waypoints are possible, then the lesser distance I value must be selected. Thus, in the first scenario $I = 16$ m, in the second scenario $I = 17$ m. Also, as previously mentioned, because the selected cases consist of one intersection, the inequality constraint given in Eq. 3 is not applied in this case.

From Fig. 2 it is clear that when the AGV velocity v is increasing, as it should be, the turning radius r also increases, at which the path would still be feasible. When the ω value was 1.5 rad/s, after the v value changed from 3 m/s to 9 m/s, the optimised turning radius r changed from 18.54 m to 22.34 m (Fig. 2, parts a and c). When the ω value was 2.5 rad/s, after the v value changed, the optimised turning radius r changed from 17.61 m to 20.21 m (Fig. 2, parts b and d). The same observation was made during the turning to the left cases. When the ω value was 1.5 rad/s, after the v value changed, the optimised turning radius r changed from 19.43 m to 23.13 m (Fig. 3, parts a and c) and when the ω value was 2.5 rad/s, the optimised turning radius r changed from 18.53 m to 21.04 m (Fig. 3, parts b and d).

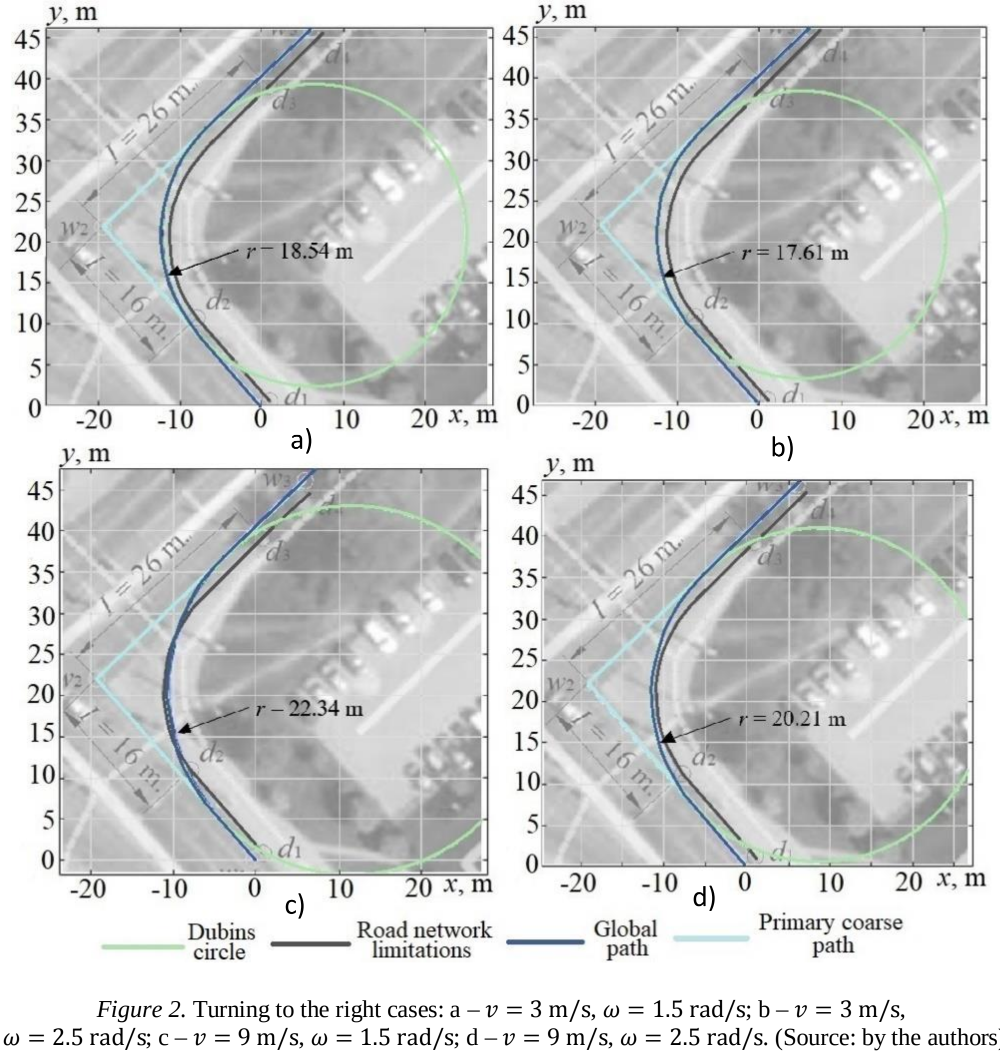


Figure 2. Turning to the right cases: a – $v = 3$ m/s, $\omega = 1.5$ rad/s; b – $v = 3$ m/s, $\omega = 2.5$ rad/s; c – $v = 9$ m/s, $\omega = 1.5$ rad/s; d – $v = 9$ m/s, $\omega = 2.5$ rad/s. (Source: by the authors)

In all the cases of both scenarios it was also observed that, when the v value is not changing and the ω value increases, the optimized turning radius r decreases. During the turning to the right cases, when the v value was 3 m/s and the ω value changed from 1.5 rad/s to 2.5 rad/s, the optimised turning radius r changed from 18.54 m to 17.61 m (Fig. 2, parts a and b). When the v value was 9 m/s, and the ω value changed from 1.5 rad/s to 2.5 rad/s, the optimised turning radius r changed from 22.34 m to 20.21 m (Fig. 2, parts c and f). Respectively, the same observation was made during the turning to the left cases. Based on the obtained results it can be stated that the proposed objective function with inequality constraints performs properly and ensures a feasible path for the AGV, while taking into account the velocity during entering the intersection, the angular velocity of the steering wheel turning and the road network (intersection) geometry.

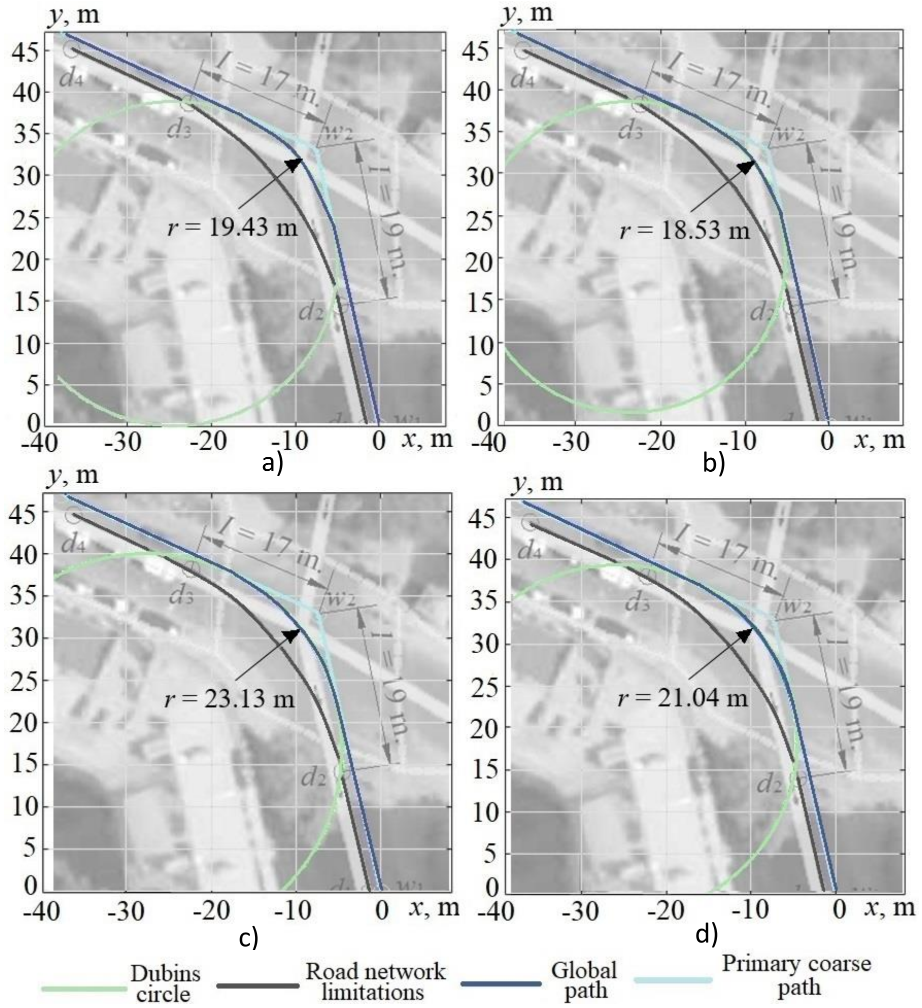


Figure 3. Turning to the left cases: a – $v = 3$ m/s, $\omega = 1.5$ rad/s; b – $v = 3$ m/s, $\omega = 2.5$ rad/s; c – $v = 9$ m/s, $\omega = 1.5$ rad/s; d – $v = 9$ m/s, $\omega = 2.5$ rad/s. (Source: by the authors)

However, from Fig. 2 it can be noticed that in some cases of turning to the right (Fig. 2, part c and d), due to the too high velocity v during the entering the intersection / the too low angular velocity of the steering wheel turning ω, the road network limitations were damaged. This can be explained by the fact that the proposed inequality constraint only evaluates the road network geometry and not its limitations, while optimising the turning radius r. This problem can be solved by adding to the constraint given in Eq. 2 or by formulating a new inequality constraint, which would evaluate the road network limitations, i.e., the minimal allowed distance between the path and the road network limitation. However, in such case, the path feasibility condition would not be satisfied. To ensure path feasibility and change the AGV velocity, the longitudinal control problem should be solved. Due to the different intersection geometry, the problem of the damaging of the road network limitations was not observed in the left turning scenario.

3.2 Experimental Application of the Algorithm

The experimental procedure was performed in an enclosed driving lot, while imitating moving in the described city road networks, i.e. intersection scenarios (Fig. 1): turning to the right and turning to the left. The intersections geometries were imitated using traffic cones (Fig 4, part a). The angular velocity of the steering wheel turning while using the automated steering device (Fig. 4, part b) was 2.65 rad/s. Thus, during turning to the right scenario, the optimised turning radius was 17.52 m and turning to the left scenario – 18.45 m. The AGV velocity during entering the intersection was controlled and maintained at the approximate values of 2.5-3.3 m/s by a human supervisor for safety reasons. The AGV angular velocity of the front wheels, the angle of the steering wheel, and the steering angle of the front wheels were the input parameters in the used controller. Overall, 4 experimental drives per each turning scenario were performed. The results of the experimental procedure are given in Fig. 5.

a) b)

Figure 4. Performed experimental procedure: a – intersections geometries imitated using traffic cones; b – automated steering device mounted on test vehicle. (Source: by the authors)

From the experimental procedure results provided in Fig. 5, it is seen that while using the autonomous test vehicle with the automated steering device, during all the experimental drives in the turning to the right scenario, the recorded moving trajectories were similar (Fig. 5, part a), and, respectively, during all the experimental drives in the turning to the left scenario, the recorded moving trajectories were also similar (Fig. 5, part b). During moving, no deviations from the predefined path, created by using the proposed algorithm, were recorded. The AGV continually followed the predefined path, i.e. the constraints and the mobility of the AGV were not neglected. However, in both cases, a discrepancy of the movement end waypoint can be seen. The discrepancy of the movement end waypoint is not related to the inaccuracies of the proposed algorithm. The discrepancy of the movement end waypoint is explained by the area limitations of the used enclosed driving lot. Based on these results, it can be stated the proposed algorithm, i.e. the objective function with the inequality constraints, which takes into account the road network geometry and the AGV manoeuvre capabilities, provides a feasible path for the AGV to follow.

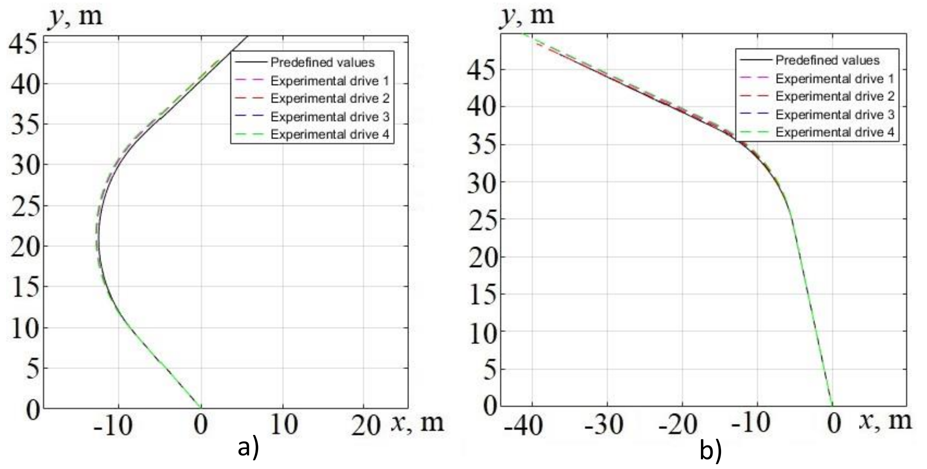


Figure 5. Results of the experimental procedure: a – turning to the right scenario; b – turning to the left scenario. (Source: by the authors)

4 Conclusions

In this paper a path planning algorithm, i.e. an objective function with inequality constraints, for a city road network is proposed. The proposed algorithm is based on the Dubins path approach, a network map of a selected road and a set of waypoints, which represent intersections and their geometry. To ensure path feasibility and safety, the algorithm takes into account the AGVs velocity during entering the intersection, the angular velocity of the steering wheel turning and the road network (intersection) geometry.

In order to investigate the performance of the proposed algorithm, a theoretical and a practical application of the proposed algorithm were performed. Based on the obtained applications results, it can be stated that the proposed algorithm performs properly and ensures a feasible path for the AGV to follow. The AGV can continually follow the predefined path, the constraints and the mobility of the AGV are not neglected. However, it was determined that, due to the reason that the proposed inequality constraint only evaluates the road network geometry and not its limitations, in some cases, the road network limitations were damaged. Seeking to ensure that the proposed algorithm would be useful in a practical way while increasing driving safety, the proposed algorithm can be improved by adding to the inequality constraints or by formulating a new inequality constraint, which would evaluate the road network limitations, i.e., the minimal allowed distance between the path and the road network limitation. However, in such case, the AGVs velocity during entering the intersection could not be deemed as a constant. Respectively, the longitudinal control problem should be solved.

References

1. Katrakazas, C.; Quddus, M.; Chen, W. H.; Deka, L. (2015) Real-time motion planning methods for autonomous on-road driving: State-of-the-art and future research directions. *Transportation Research Part C 60*, 416–442.
2. Chu, K.; Kim, J.; Jo, K.; Sunwoo, M. (2015) Real-time path planning of autonomous vehicles for unstructured road navigation. *International Journal of Automotive Technology 16(4),* 653–668.
3. Kala, R. (2016) *On-road intelligent vehicles. Motion planning for intelligent transportation system*. 1st edition. Elsevier, Kidlington.
4. Gu, T.; Dolan, J. M. (2012) On-road motion planning for autonomous vehicles. *Intelligent Robotics and Applications*, 588–597.
5. Alcala, E.; Puig, V.; Quevedo, J.; Escobet, T.; Comasolivas, R. (2018) Autonomous vehicle control using a kinematic Lyapunov-based technique with LQR-LMI tuning. *Control Engineering Practice 73*: 1–12.

6. Hu, W.; Chen, L.; Tang, B.; Cao, D.; He, H. (2018) Dynamic path planning for autonomous driving on various roads with avoidance of static and moving obstacles. *Mechanical Systems and Signal Processing 100*, 482–500.
7. Bae, I.; Moon, J.; Park, H.; Kim, J. H. (2013) Path generation and tracking based on a Bezier curve for a steering rate controller of autonomous vehicle. In: *Proceedings of the 16th International IEEE Annual Conference on Intelligent Transportation Systems*, pp. 436–441. IEEE, Netherlands.
8. Park, B.; Lee, Y. C.; Han, W. H. (2014) Trajectory generation method using Bezier spiral curves for high speed on-road autonomous vehicles. In: *IEEE International Conference on Automation Science and Engineering*, pp. 927–932. IEEE, Taiwan.
9. Hegedus, R.; Becsi, T.; Aradi, S.; Gaspar, P. (2017) Model based trajectory planning for highly automated road vehicles. *IFAC-PapersOnLine* 50(1), 6958–6964.
10. Kim, J.; Jo, K.; Kim, D.; Chu, K.; Sunwoo, M. (2013) Behaviour and path planning algorithm of autonomous vehicle A1 in structured environments. In: *8th IFAC Symposium on Intelligent Autonomous Vehicles*, pp. 36–41. IFAC, Australia.
11. Boroujeni, Z.; Goehring, D.; Ulbrich, F.; Neumann, D.; Rojas, R. (2017) Flexible Unit A-star Trajectory Planning for Autonomous Vehicles on Structured Road Maps. In: *IEEE International Conference on Vehicular Electronics and Safety*, pp. 7–12. IEEE, Austria.
12. Gu, T.; Snider, J.; Dolan, J. M.; Lee, J. (2013) Focused Trajectory Planning for autonomous in-road driving. In: *Intelligent vehicles Symposium (IV)*, pp. 547–552. IEEE, Australia.
13. Takano, G.; Obayashi, M.; Uto, K. (2017) Posture-to-posture trajectory planning for an autonomous car using triple clothoid segments. In: *56th Annual Conference on Decision and Control*, pp. 299–306. IEEE, Australia.
14. Li, C.; Li, X.; Li, J.; Zhu, Q.; Dai, B. (2017a) Reference path optimization for autonomous ground vehicles driving in structured environments. In: *2nd IEEE International Conference on Computational Intelligence and Applications*, pp. 172–176. IEEE, China.
15. Li, C.; Li, X.; Li, J.; Zhu, Q.; Dai, B. (2017b) Trajectory Planning for Autonomous Ground Vehicles Driving in Structured Environments. In: *9th International Conference on Intelligent Human-Machine Systems and Cybernetics*, pp. 41–45. IEEE, China.
16. Kikutis, R. (2018) *Research on the accuracy of algorithms for autonomous aircraft navigation*. Doctoral dissertation. Vilnius Gediminas Technical University.
17. Bayar, G.; Bergerman, M.; Konukseven, E. I.; Koku, A. B. (2016) Improving the Trajectory Tracking Performance of Autonomous Orchard Vehicles Using Wheel Slip compensation. *Biosystems Engineering* 146, 149–164.

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 21-29
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

APPLYING METHODS OF ARTIFICIAL INTELLIGENCE FOR OPTIMIZATION IN PRODUCTION AND LOGISTICS

Sebastian Lang

Otto von Guericke University Magdeburg
Magdeburg, Germany, Universitätsplatz 2
sebastian.lang@ovgu.de

This paper discusses the application potentials of Artificial Intelligence methods to solve optimization problems in production and logistics. For this purpose, this paper introduces a first concept of a framework, which utilizes methods of artificial intelligence and discrete event simulation to tackle optimization problems. Besides a general explanation of the framework, the paper provides theoretical fundamentals about artificial intelligence and an insight into the related research concerning the application of artificial intelligence methods for optimization in production and logistics.

Keywords: Artificial Neural Network, Fuzzy Logic, Evolutionary Algorithm, Optimization, Production, Logistics

1. Introduction

In the field of production and logistics, mathematical optimization is an everyday necessity. For instance, in a manufacturing system, which produces a high variety of products, planers have to schedule the production of goods in order to meet customer deadlines. On the other hand, the production plan shall be designed to support a continuous production flow, as well as a high utilization of machines. To provide another example, let us consider a mass production with low variant diversity. Here, the planning department need to calculate the optimal production volume, which needs to be sufficient to serve future customer demands, but which should also be as small as possible to reduce the number and sizes of stocks and the number of products which are work in process.

The daily optimization problems to solve are often highly complex. Many of those problems belong to complexity class *np-hard*. The abbreviation *np* stands for nondeterministic polynomial time. This means that only a nondeterministic machine can solve those problems within an acceptable computational time (Zimand, 2004). The reason for this is that the solution space of an np-hard problem grows in a non-polynomial manner, if the problem size only increases by one variable. In consideration of the fact that a conventional computer can only process data deterministically, the state of scientific knowledge is that no algorithm exists which is able to calculate the provable optimal solution for an np-hard problem without enumerating the complete solution space (Hromkovič, 2014). Therefore, production planers usually apply specific heuristics or metaheuristics instead to approximate the optimal solution.

However, specific heuristics and metaheuristics have some drawbacks making their application challenging. A specific heuristic is only suitable for a particular problem. Therefore, if planners face a new optimization problem, they need to develop a new heuristic, or they need to investigate whether or not a suitable heuristic already exists. Regardless of whether a new heuristic needs to be developed or if a given heuristic can be applied, both methods are laborious and require expert knowledge in operations research, programming and the problem itself. Metaheuristics, on the other hand, are theoretically suitable for every kind of optimization problem because they search for solutions without requiring precise information about the problem structure (Blum and Roli, 2003). Still, a problem related adaptation needs a fundamental knowledge about how the metaheuristic works and how adjustments of the metaheuristic's control variables influence the solution process. Furthermore, the non-problem tailored search for solutions can lead to a high computational effort, since every solution candidate need to be evaluated (for instance, by computationally intensive simulation models).

In the current decade, researchers achieved some significant breakthroughs in the field of artificial intelligence (Krizhevsky *et al.*, 2012; Silver *et al.*, 2016). On the one hand, these breakthroughs can be explained by the technical progress of computer hardware, which has a direct influence on the performance and therefore on the potentials for application of AI technologies. On the other hand, AI researchers still invest much effort to improve the existing AI methods. A couple of these methods have some interesting properties, which may make them relevant as an alternative solution approach for optimization problems.

This paper presents the first concept of a solver for optimization problems, further named as AI-Optimization-Framework (AIOF), which combines the AI method "artificial neural network" together with discrete event simulation. The upcoming section contains a short summary of the theoretical principles of AI and presents some fundamental AI methods. The third section contains some exemplary related research that utilizes AI methods for optimization problems. The fourth section presents the solver concept, and the last section states future research challenges.

2. Artificial Intelligence

The term *Artificial Intelligence* is not clearly defined, since there are several literature sources providing different explanations of the term (Jang *et al.*, 1997). Ertel (2016) provides an overview of definitions for artificial intelligence, which arose over time. In his opinion, the following definition is most likely to apply: "Artificial Intelligence is the study of how to make computers do things at which, at the moment, people are better" (Rich, 1983).

This definition seems accurate, because it reflects the current driving trends in AI research. For instance, the further developments of artificial neural networks has led to significant improvements of computational image and speech recognition. Both are primary examples, in which humans still outperform computers.

In this section, the subject of interest is how to make computers "intelligent". The field of AI provides several methods for this purpose. Similar to the definition of AI, the research community does not agree about how to classify AI methods. Therefore, one can find various methods in the literature which claimed to be AI, but which in turn other researchers do not consider as such. In this paper, to classify AI methods, we rely on the collective name *Computational Intelligence* (CI), which "[...] comprises concepts, paradigms, algorithms, and implementations to develop systems that exhibit intelligent behaviour in complex environments" (Kruse *et al.*, 2016). CI includes three fundamental methods (VDI/VDE 3550 Part 1, 2001):

- Artificial Neural Networks (ANN)
- Fuzzy Logic (FL)
- Evolutionary Algorithms (EA)

According to Haykin (1999), an ANN is a "[...] massively parallel distributed processor consisting of simple processing units, which has a natural propensity for storing experiential knowledge and making it available for use". A processor unit is called *Neuron*. Neurons can process multiple input streams and output one result. To accomplish this, the activation function within the neuron calculates the output value, considering the given input data. Neurons are organized in layers. An ANN consists of at least one layer. More usual, however, are network structures with three or more layers, whereby one input layer directly processes incoming data and one output layer calculates a corresponding solution. A neuron maintains connections to other neurons, which usually belong to adjacent layers. These weighted connections are called *Synapses*. They determine how strong a neuron reacts on value changes of an upstream neuron. ANN apply machine-learning algorithms to find a relationship between input and output data.

For this purpose, the majority of machine-learning algorithms analyse several reference data sets of a problem and adjust the synapse weights of the ANN iteratively, until no significant improvement is possible anymore. After successfully completing a sufficiently large training period, an ANN is able to estimate output values for similar problems.

FL is an alternative approach to conventional Boolean logic. It provides a formalization of *Approximate Reasoning* and is closely connected to the theory of fuzzy sets, which describe sets of related classes with indistinct boundaries (Zadeh, 1994). The principles of fuzzy logic allows a machine to transform qualitative information into quantitative data and vice versa. The main idea of fuzzy sets is to create a link between linguistic and numeric variables (Zadeh, 1975). In this context, each value of a linguistic variable corresponds to an interval of values of the numeric variable. In contrast to conventional quantization of values, the boundaries of the intervals within a fuzzy set are overlapping. As an example, let us introduce the variable Temperature. We assume that Temperature can obtain the string values “cold”, “warm” and “hot”. The corresponding numerical intervals are (0, 35), (25, 60) and (50, 100) centigrade. In consequence, temperatures between 25 and 35 centigrade can be considered as “cold” or “warm” and temperatures between 50 and 60 centigrade as “warm” or “hot”. For the resulting fuzzy intervals (25, 30) and (50, 60), there are two probability functions describing the most likely membership of each possible numeric value to each possible linguistic value. Describing linguistic variables with fuzzy sets rather than strictly defined intervals seems more reasonable, since fuzzy sets consider the subjectivity of perception.

EA describes a class of optimization methods, which search for solutions according to the behaviour of biological evolution (Weicker, 2015). Popular examples for EA are genetic algorithms or scatter search, which are detailed in (Gendreau and Potvin, 2010). Each EA has its own scheme to search for an optimum, but the basic process is always the same: In an initial step, the EA randomly creates a set of start solutions also known as population. Despite the randomness of the process, the EA tries to meet specific requirements for the initial population, for instance maintaining a large-scale distribution of population members across the complete solution space. After the initialization, the EA enters the iterative search process. In the first step, the EA generates a subset of solutions with the best results. Based on the members of this subset, the EA creates in the second step new solution candidates. For this purpose, the EA can “mutate” existing solutions, which means that the solution vector of the candidate changes in some specific manner. Furthermore, the EA can “pair” two members of the subset, which means that the algorithm combines the vectors of the “parent” solutions in a certain way to generate a “child” solution. The EA saves each mutated or new generated solution candidate within the subset. In the third step, the EA replaces a specific number of population members, which provide the worst solutions, with a corresponding number of subset members providing the best solutions. Afterwards, the EA deletes the subset and may goes into the next iteration.

3. Related Research

As shown in the previous section, the field of AI methods is broad and a comprehensive literature review would go beyond the scope of this paper. This section merely provides a highly aggregated overview of related publications. The investigation results are part of a systematical literature review, which is still in process. Therefore, the papers referenced in this section do not represent a holistic view on the research about “AI for optimization”, but rather a first insight. Furthermore, this section will not discuss publications describing the application of EA for optimization. As described in the introduction to this paper, the application of metaheuristics is considered to be state-of-the-art for solving optimization problems. Since every EA is a metaheuristic (Burke and Kendall, 2005), a literature review about EA for optimization would be pointless. A comprehensive review about evolutionary algorithms and other metaheuristics for combinatorial optimization problems provide Blum and Roli (2003) and Bianchi *et al.* (2005).

Concerning the application of ANN for optimization, Hopfield neural networks are probably the oldest known ANN methods. The application of Hopfield networks to solve the Traveling Salesman Problem (TSP) was already proposed by Hopfield and Tank (1985). The main characteristic of a Hopfield network is the interconnection of all neurons. Hence, a differentiation of neurons in input, output and hidden neurons is not possible. There are two ways to activate neurons in a Hopfield network. If all neurons are activated at the same time, the processing of data will never stop, because all neurons respond on changes of adjacent neurons in an infinite loop. Therefore, neurons in a Hopfield network are usually asynchronously activated. As a result, the network will reach a steady state after certain steps in which an active neuron cannot change to an inactive state and vice versa. In the following, we will summarize briefly how to solve the TSP with a Hopfield network. An extensive description is provided, for instance, in (Kruse *et al*., 2016). Considering a TSP with n locations, the corresponding Hopfield network has to consist of n^2 neurons. Thus, a neuron represents a location to consider within the route as well as the corresponding rank indicating when a location shall be visited. In the next step, the objective function and the restrictions of the TSP need to be transformed to an energy function. The energy function has two characteristics: First, the function indicates whether the Hopfield network is in a steady state. Second, since the energy function derives from the TSP, it expresses also a solution for the TSP. Thus, a Hopfield network is in a steady state and finds an optimum for the TSP, when the function reaches a minimum. The minimum found is probably local, since the sequence, in which neurons of a Hopfield network are activated, leads to different results. Hence, it is advisable to initialize the Hopfield network several times to get closer to a global optimum. However, the optimization with Hopfield networks is in practice not common. Besides some arithmetical and computational problems, for instance discussed in (Kruse *et al*., 2016; Joya *et al*., 2002), the major drawback of Hopfield networks is the representation of the entire solution space of an optimization problem by neurons. Hence, complex problems require large-scale Hopfield networks. Furthermore, the number of possible activation sequences grows hyper-exponentially with increasing number of neurons. In contrast to feedforward ANN, a Hopfield network does not allow additional neurons to consider, for instance, information about the current system state or attributes of the current decision object. Hence, the search for an appropriate activation sequence within a Hopfield network seems comparable to the non-problem related search for an optimal solution of any metaheuristic.

Looking on recent research, most of the publications propose the application of ANN for scheduling problems, by which the proposed solution approaches determine an optimal assignment of customer orders to machines or an optimal sequence of already assigned customer orders. So far, three different approaches could be identified to apply ANN for scheduling:

- A set of priority dispatching rules controls the operations in the production system. Only one priority dispatching rule can be enabled at the same time. In this scenario, an ANN selects for a specific period of time an appropriate dispatching rule by analyzing the current system state. For instance, Arzi and Iaroslavitz (1999), Azadeh *et al.* (2013) and Bergmann *et al*. (2014) presents this approach.
- The authors apply ANN to estimate parameters for a self-developed priority dispatching rule. The estimated parameters are coefficients of the priority index function, which have an unknown relation to the problem itself (Park *et al*., 2000).
- Another possibility to utilize ANN for scheduling problems describes Hammami *et al*. (2017). Here, the ANN decides directly on which machine a customer order should be allocated. The decision is based on attributes of the customer order, such as due date or product family, as well as, the current system state.

So far, only three papers could be investigated, which describe fuzzy-logic based approaches for optimization. Medaglia *et al*. (2002) presents a fuzzy-logic based expert system to evaluate solutions of a simulation optimization framework. The authors argue that determining the precise performance limit of a system, for having a benchmark to evaluate solution candidates, is for complex problems not feasible. Instead, expert knowledge of analysts and decision makers, represented by linguistic variables, can also express the quality of a solution. Pugh (1997) applies fuzzy logic for labour allocation within a manufacturing system. Here, the queue size in front of a machine and the intensity of the corresponding process are the subjects of two membership functions. By calculating the product of the outputs from both functions, the simulation model receives the probability for assigning a worker to the corresponding machine. The simulation model decides to allocate a worker, if a randomly generated number is smaller than the calculated probability. Samanta and Al-Araimi (2001) propose a fuzzy-logic based inventory control system to consider the dynamic, stochastic and uncertainty of the customer demand. The task of the inventory control system is to decide about the production amount in order to maintain a desired inventory level, which varies over time. The system performs the decision depending on the difference between the current desired and the actual inventory level. The authors apply fuzzy logic to assess the size of this difference in comparison with tracked differences from the past. Based on the identified membership, a specific correction parameter adjusts the desired production amount. In conclusion, the proposed system analyses desired inventory levels from the past, in order to determine a production amount, which will presumably meet future fluctuations of the desired inventory level.

4. A First Concept for an AI-based Optimization Framework

Compared to metaheuristics, the solution approaches presented in the previous section suffer from some shortcomings. Looking on the ANN-based solution approaches, one may criticize that the rule-based allocation and sequencing of customer orders does not respect the characteristics and particularities of a specific optimization problem. Metaheuristics do not consider both as well, but instead they are able to search the whole solution space of an optimization problem for promising solution candidates. Another drawback of the ANN-based solution approaches is the merely partial view on the optimization problem itself during the decision-making process. More precisely, the described approaches are considered as real-time scheduler, which only analyse the current system state and the attributes of the customer order to be assigned, when a decision needs to be processed. Therefore, those approaches do not allow a holistic view on an optimization problem, i.e. they are unable to identify potential synergies and influences of a performed decision on upcoming customer orders. Hence, the AIOF has to fulfil the following requirements:

- Like metaheuristics, the AIOF should suggest completely described solutions for a given optimization problem with a given input. This excludes, for instance, the recommendation of a system behaviour described by a priority dispatching rule.
- During the calculation of a solution, the AIOF has not only to consider the current state of the system and the attributes of the currently analysed decision object. For a local decision, it should also be able to consider important information about decision objects, which it would analyse at a later point of time. Furthermore, the framework has to assess the value of a local decision, before settling that decision, for instance by estimating the resulting system state.
- The computational time for calculating a result has to be sufficiently low to face operational decisions with a short-term due date. Since there is no general definition of when a due date is considered as short-term, the user of the AIOF needs to be able to scale the investment of computational effort and computational time for calculating a result.

Metaheuristics are also scalable in terms of computational effort and computational time. For instance, metaheuristics allow to determine a maximum time limit to search for solutions or a maximum number of solution candidates to evaluate. However, the probability for finding the optimal solution falls with decreasing time to search for solutions. In contrast, the solution quality of ANN and FL is not related to the available computational time, because both methods determine a solution by experiential estimating instead of searching. From this point of view, a fourth requirement results that concerns the significance and reasonability of the AIOF:

- If only a minor time span is available to setup and carry out an optimization process, the AIOF has to outperform any searching metaheuristic in terms of solution quality.

The concept and design of the proposed framework shall reflect these requirements. Figure 1 presents the basic structure of the AIOF.

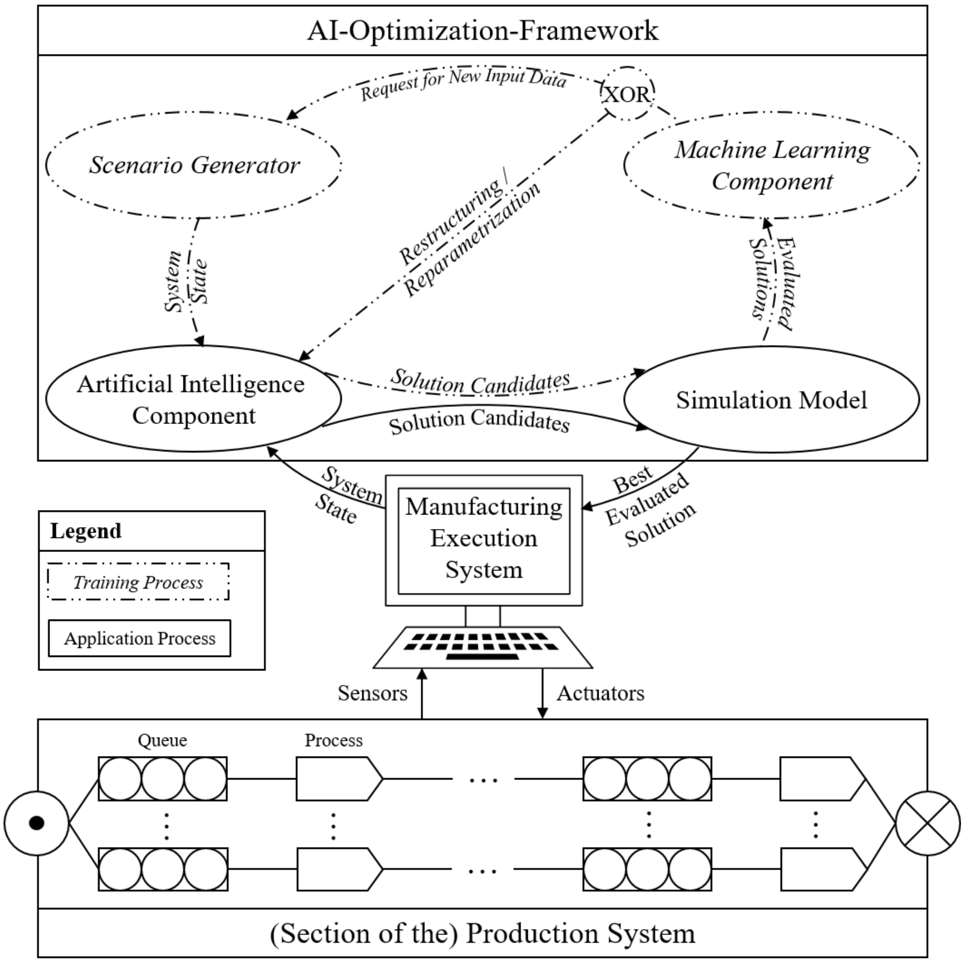


Figure 1. Conceptual model of the AIOF

As illustrated, the framework consists of four components:

- An AI component for optimization mainly based on an ensemble of ANN. The ANN differ in terms of their network structure and synapse weights.
- A simulation component for evaluating the solution candidates
- A machine-learning (ML) component which adjust the weights, thresholds and may also the network structure of the ANNs during the training period.
- A scenario generator to create training data, based on the production system to be analysed and the optimization problem to be solved

Before a production system can apply the AIOF, the AI component requires a *Setup Phase*. Within the setup phase, the AI component receives training data from the scenario generator. In the next step, every ANN of the ensemble suggests a problem solution, based on its specific structure and synapse weights. The simulation component sequentially utilizes the corresponding output data to calculate user-specified KPIs. Furthermore, the results of each simulation experiment are aggregated to a general system performance indicator. Afterwards, the ML component checks, whether the system performance indicator exceeds a specific threshold. If false, the ML component adjusts the parameters of the corresponding ANN. If true, the ML component sends a message to the scenario generator to create a new problem instance. Once the ML component has adjusted the AI component for a satisfying number of problem instances, the AIOF is prepared for the *Application Phase*. Within the application phase, the AIOF receives input data from the MES of the production system. Still, the simulation component evaluates the quality of each solution candidate generated by a specific ANN of the ensemble. The AIOF will send back the most promising solution candidate as result to the MES.

A successful application of the AIOF mainly depends on the AI component. So far, there are several ideas about the design of the AI component. However, this paper will only contain the description of the most promising concept so far. Figure 2 represents a pseudo code, which describes the determination of a solution candidate for any given optimization problem.

```
algorithm ANN_solution_process

  input: Collection E[n] consisting of n trained ANN;
         Input matrix I[k][m] with m input datasets,
           whereby each input dataset is related to a
           decision object with k attributes;
         Input system state vector S[l] representing
           l system state variables;

  output: Solution matrix Y[n][m] consisting of m
           solutions, whereby each solution contains
           results for n decision objects;

  for i := 1 to n do
     set S[1, ..., l] depending on the initial system state;
     for j := 1 to m do
        estimate result Y[i][j] for input dataset j;
        update S[1, ..., l] depending on settled decision;
     end
  end
```

Figure 2. Proposed solution determination process of the AI component

In order to give an example how the algorithm in Figure 2 operates, let us consider a flow shop scheduling problem with 40 jobs to be scheduled. In this scenario, a job corresponds to a decision object. Every ANN of the ensemble (represented by the first for-loop) would process 40 decisions (represented by the second for-loop) to determine a complete solution vector, whereby each decision is determined in dependence of k decision object attributes and l system state variables. The attributes of a job can be, for instance, its due date, its priority, its product family, and so on. Variables representing the system state can be for instance the current setup of machines (represented by the last scheduled job), the number of jobs of each family still to be scheduled or the average of job attributes calculated over the number of jobs still to be scheduled, such as due date, priority, and so on. Since the system state changes in dependence of settled decisions, the corresponding variables need to be updated after every decision. Hence, different sequences to consider decision objects results in different developments of the system state during the solution process. In consequence, the order in which the AIOF considers decision objects for the determination of a solution could have a major influence on the optimization result. On the one hand, this could be beneficial, because a single ANN is able to suggest different solutions for one input dataset simply by permuting the columns of the input matrix *I*. Thus, the number of ANN to be trained could be possibly reduced. On the other hand, the number of solutions to be evaluated increases significantly, which results in a higher computational time to determine the best result. Therefore, we will also investigate, if there is any meaningful way to pre-sort the datasets to achieve an appropriate input sequence.

5. Future Research Challenges

So far, there are still some open problems, which the current concept ideas cannot yet resolve:

- How can be ensured that the AIOF considers mathematical constraints of the optimization problem during the solution process? Since a trained ANN is only able to estimate exactly one solution for a specific input data stream, it is highly important that the resulting solution is feasible.
- How should the AIOF react on unexpected changes regarding the statistical properties of input data? Significant changes of input data may lead to unsuitable solutions. Therefore, it is important to develop an adaption strategy, which is able to quickly adjust the parameters of an ANN
- Which KPIs are meaningful to represent the attributes of upcoming decision objects, while the AIOF determines a decision for a currently treated decision object? The consideration of such KPIs as input neurons could be important to maintain a holistic view on the optimization problem and to perform foresighted decisions.

These research items as well as a prototypical implementation of the AIOF will be subject of future publications.

References

1. Arzi, Y. and Iaroslavitz L. (1999) Neural Network-Based Adaptive Production Control System for a Flexible Manufacturing Cell under a Random Environment. *IIE Transactions*, 31 (3), 217–230. DOI: https://doi.org/10.1080/07408179908969822.
2. Azadeh, A., Maleki Shoja, B., Moghaddam, M., Asadzadeh, S.M. and Akbari, A. (2013) A Neural Network Meta-Model for Identification of Optimal Combination of Priority Dispatching Rules and Makespan in a Deterministic Job Shop Scheduling Problem. *The International Journal of Advanced Manufacturing Technology*, 67 (5–8), 1549–1561. DOI: https://doi.org/10.1007/s00170-012-4589-y.
3. Bergmann, S., Stelzer, S. and Strassburger, S. (2014) On the Use of Artificial Neural Networks in Simulation-Based Manufacturing Control. *Journal of Simulation*, 8 (1), 76–90. DOI: https://doi.org/10.1057/jos.2013.6.
4. Bianchi, L., Dorigo, M., Gambardella, L.M. and Gutjahr, W.J. (2005) A Survey on Metaheuristics for Stochastic Combinatorial Optimization. *Natural Computing*, 8 (2), 239–287. DOI: https://doi.org/10.1007/s11047-008-9098-4.
5. Blum, C. and Roli, A. (2003) Metaheuristics in Combinatorial Optimization: Overview and Conceptual Comparison. *ACM Computing Surveys,* 35 (3), 268–308. DOI: https://doi.org/10.1145/937503.937505.
6. Burke, E.K. and Kendall, G. (2005) *Search Methodologies: Introductory Tutorials in Optimization and Decision Support Techniques*. New York: Springer Science+Business Media.
7. Ertel, W. (2016) *Grundkurs Künstliche Intelligenz: Eine praxisorientierte Einführung*. Wiesbaden: Springer Vieweg.
8. Gendreau, M. and Potvin, J.-Y. (2010) *Handbook of Metaheuristics*. New York: Springer Science+Business Media.
9. Hammami, Z., Mouelhi, W. and Lamjed, B.S. (2017) On-line Self-Adaptive Framework for Tailoring a Neural-Agent Learning Model Addressing Dynamic Real-Time Scheduling Problems. *Journal of Manufacturing Systems*, 45, 97–108. DOI: https://doi.org/10.1016/j.jmsy.2017.08.003.
10. Haykin, S. (1999) *Neural Networks: A Comprehensive Foundation*. Dehli: Pearson Education.
11. Hopfield, J.J. and Tank, D.W. (1985) "Neural" Computation of Decisions in Optimization Problems. *Biological Cybernetics*, 52 (3), 141–152. DOI: https://doi.org/10.1007/BF00339943.
12. Hromkovič, J. (2014) *Theoretische Informatik. Formale Sprachen, Berechenbarkeit, Komplexitätstheorie, Algorithmik, Kommunikation und Kryptographie*. Wiesbaden: Springer Vieweg.
13. Jang, J.-S.R., Sun, C.-T. and Mizutani, E. (1997) *Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence*. Upper Saddle River: Prentice Hall.

14. Joya, G., Atencia, M.A. and Sandoval, F. (2002) Hopfield Neural Networks for Optimization: Study of the Different Dynamics. *Neurocomputing*, 43 (1–4), 219–237. DOI: https://doi.org/10.1016/S0925-2312(01)00337-X.
15. Krizhevsky, A., Sutskever, I. and Hinton, G.E. (2012) ImageNet Classification with Deep Convolutional Neural Networks. In: *NIPS'12 Proceedings of the 25th International Conference on Neural Information Processing Systems - Volume 1*, Lake Tahoe, December 2012. Red Hook: Curran Associates Inc., pp. 1097–1105.
16. Kruse, R., Borgelt, C., Braune, C., Mostaghim, S. and Steinbrecher, M. (2016) *Computational Intelligence: A Methodological Introduction*. London: Springer.
17. Medaglia, A.L., Fang, S.-C. and Nuttle, H.L.W. (2002) Fuzzy Controlled Simulation Optimization. *Fuzzy Sets and Systems*, 127 (1), 65–84. DOI: https://doi.org/10.1016/S0165-0114(01)00153-1.
18. Park, Y., Sooyoung, K. and Young-Hoon, L. (2000) Scheduling Jobs on Parallel Machines Applying Neural Network and Heuristic Rules. *Computers & Industrial Engineering*, 38 (1), 189–202. DOI: https://doi.org/10.1016/S0360-8352(00)00038-3.
19. Pugh, G.A. (1997) Fuzzy Allocation of Manufacturing Resources. *Computers & Industrial Engineering*, 33 (1–2), 101–104. DOI: https://doi.org/10.1016/S0360-8352(97)00050-8.
20. Rich, E. (1983) *Artificial Intelligence*. New York: McGraw-Hill.
21. Samanta, B. and Al-Araimi, S.A. (2001) An Inventory Control Model Using Fuzzy Logic. *International Journal of Production Economics*, 73 (3), 217–226. DOI: https://doi.org/10.1016/S0925-5273(00)00185-7.
22. Silver, D., Huang, A., Maddison, C.J., Guez, A., Sifre, L., van den Driessche, G., Schrittwieser, J., Antonoglou, I., Panneershelvam, V., Lanctot, M., Dieleman, S., Grewe, D., Nham, J., Kalchbrenner, N., Sutskever, I., Lillicrap, T., Leach, M., Kavukcuoglu, K., Graepel, T. and Hassabis, D. (2016) Mastering the Game of Go with Deep Neural Networks and Tree Search. *Nature*, 529 (7587), 484–489. DOI: https://doi.org/10.1038/nature16961.
23. VDI/VDE 3550 Part 1. (2001) *Artificial neuronal network in automation: Terms and definitions*. Berlin: Beuth.
24. Weicker, K. (2015) *Evolutionäre Algorithmen*. Wiesbaden: Springer Vieweg.
25. Zadeh, L.A. (1975) The Concept of a Linguistic Variable and its Application to Approximate Reasoning–II. *Information Sciences*, 8 (4), 301–357. DOI: https://doi.org/10.1016/0020-0255(75)90046-8.
26. Zadeh, L.A. (1994) Fuzzy Logic, Neural Networks, and Soft Computing. *Communications of the ACM*, 37 (3), 77–84. DOI: https://doi.org/10.1145/175247.175255.
27. Zimand, M. (2004) *Computational Complexity: A Quantitative Perspective*. Amsterdam: Elsevier.

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 30-36
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

SIMULATION-DRIVEN ARTIFICIAL INTELLIGENCE FOR SOLVING STOCHASTIC COMBINATORIAL OPTIMIZATION PROBLEMS IN PRODUCTION AND LOGISTICS

Ilya Jackson [1]**, *Jurijs Tolujevs*** [2]

[1,2] *Transport and Telecommunication Institute (TTI)*
Lomonosova iela 1, Riga, Latvia
[1] *jcksnl93@gmail.com*
[2] *tolujevs.j@tsi.lv*

After completing an extensive review of related work, this paper describes a way to extend general simulation-optimization framework for solving stochastic combinatorial optimization problems related to production and logistics. The paper discusses that since with the increased integration of simulation in the product life cycle management, the requirements for simulation have changed significantly, a Digital Twin simulation paradigm along with deep learning-based artificial intelligence are naturally required to be incorporated into the simheuristic workflow.

Keywords: stochastic combinatorial optimization, industrial artificial intelligence, simheuristics, Digital Twin

1. Introduction

Modern markets are exceedingly competitive. Industries are facing unceasingly growing pressure on both prices and quality. Besides that, the company is required to swiftly respond to stochastic market conditions. Incorrect industrial policy leads not only to corporate losses, but also to overproduction and excessive resource consumption which is extremely harmful for a humanity as a whole. In this regard, traditional "binge-and-purge" policy is not appropriate any more. Each penny lost in variable costs inevitably entails huge additional expenses along with reduced efficiency. That is why in the field of production and logistics, mathematical optimization has recently become a daily routine. In the context of this paper, optimization may be defined as any methodologically supported process that makes a decision as efficient or functional as possible in three main levels of activities: the strategic level of production and inventory; the tactical level of manufacturing operations; and the operational level of process and material flow planning. Such decisions may include cost minimization, quality and improvement, energy consumption and so on.

Above-mentioned decision-making issues in real world may be modelled as NP-hard combinatorial optimization problems with stochastic conditions (Bianchi *et al*., 2009). The world is full of uncertainty, which frequently makes classical deterministic approaches unsuitable due to excessive simplicity. Since stochastic combinatorial optimization problems are commonly characterized by the necessity for nearly-optimal solutions in feasible computing times, metaheuristics is used so widely to solve them. Moreover, metaheuristics provides a gargantuan arsenal of random search methods and parallelization paradigms. However, stochastic nature of such problems requires to take into account random components that may be contained either in the objective function or in the constraints. The popular solution for that is to utilize a simulation instead of an objective function in traditional form and apply the metaheuristics of some sort to find such simulation adjustments that lead to the optimal output. Such approaches are conventionally called simulation–based optimization (Subramanian *et al*., 2000) or "simheuristics" (Juan *et al*., 2014). This combined approach provides a modeller with a tool to deal with real-world stochasticity in unconstrained way and assess alternative candidate-solutions by risk and reliability analysis.

In the past decade, computer simulation has become a multi-tool for understanding the dynamics of industrial systems. Leading companies intensively apply simulation for operational and strategic planning. However, with the increased integration of simulation in the product life cycle management, the requirements have changed significantly. Increasing product variants and customisable products require more flexible production systems. All this gave a birth to a new simulation paradigm. The paradigm that requires modelling of manufacturing and other systems via the concept of virtual environment and the use of industrial-specific artificial intelligence for process control, which includes self-organization to the operation systems. Such a simulation paradigm is called Digital Twin. This concept extends the use of simulation modelling to all phases of the product life cycle, where the products are first developed and tested in full detail in a virtual environment, and the subsequent phases use the information generated and gathered by the previous product life cycle phases. Combining the real life data with the simulation models from design enables accurate productivity and maintenance predictions based on the realistic data. A Digital Twin allows an AI-system to train on a virtual machine until it has sufficient “skills” to operate the real inventory or another industrial system. Digital Twin accelerates learning process providing necessary training data (Goossens, 2017). In this regard, the research goal is to discuss the concept of Digital Twin along with deep learning-based artificial intelligence as potential augmentations for the existing framework of simheuristics.

2. Simulation-driven Approach

As it is mentioned in the recent research (Juan *et al*., 2015), real-life stochastic combinatorial optimization problems may be reformulated as a simulation in a natural way. Thus, the hybridization of metaheuristics and simulation techniques promises to be an efficient solution for stochastic combinatorial optimization problems. According to Swisher *et al.* (2000) simulation-driven optimization or simheuristics is defined as a ‘‘structured approach to determine optimal input parameter values, where optimal is measured by a function of output variables – steady-state or transient – associated with a simulation model’’. In this regard, the optimization procedure utilizes the outputs from the simulation model, which evaluates the performance of a given solution. In other words, the method aims to use a simulation instead of an objective function in traditional form and apply the metaheristic search to find such simulation adjustments that would lead to the optimal output (Fig. 1). In such a method, the iterative searching process has to assess the quality of feasible individual solutions, highlighting the promising ones. The process continues until the search time runs out. Immediately after this, a decision maker selects a final solution among promising with regard to a preferable risk policy.

According to Pidd (1998), the simulation provides a natural way to introduce randomness of stochastic process. Furthermore, following simheuristic approach real-world stochasticity may be modelled throughout the best-fit probability distribution. The distribution may be either theoretical or empirical, without the need to be approximated to normal or exponential. Roughly speaking, Simulation-based optimization has been known for some decades. In the academic literature it is possible to track multiple examples of such applications in the field of manufacturing and production. For example, Dengiz and Alabas (2000) propose a tabu-search algorithm, in conjunction with a simulation model of a just-in-time system, to find the optimum control policy that meet production demands. However, the field has significantly developed in the last decade, fertilized by the evolution in computational capacity and the development of advanced optimization techniques. The study conducted by Subramaniam and Gosavi (2004) may be considered as an example of such development. As far back as 14 years ago the authors managed to present a simulation-driven approach aimed at solving a stochastic material-dispatching system in a retailer network. The considered problem is one of determining the optimal number of trucks and quantities to be dispatched. The authors developed a model that accommodates several real-life considerations. Subramaniam and Gosavi applied two optimization techniques, namely simulated annealing and neuro-response surfaces to solve the problem of dispatching material between a single warehouse and several retailers. In the same year Jung *et al.* (2004) attempted to tackle a supply chain management problem under demand uncertainty. The authors have devised an optimization-based simulation framework solving the problem using a rolling horizon within the simulation model. This procedure is repeated iteratively, looking for the appropriate refinements to the safety stock levels in order to accommodate the uncertainty of demand. It is very important to note that Jung *et al.* extend this study to multi-stage supply chains later (2008).

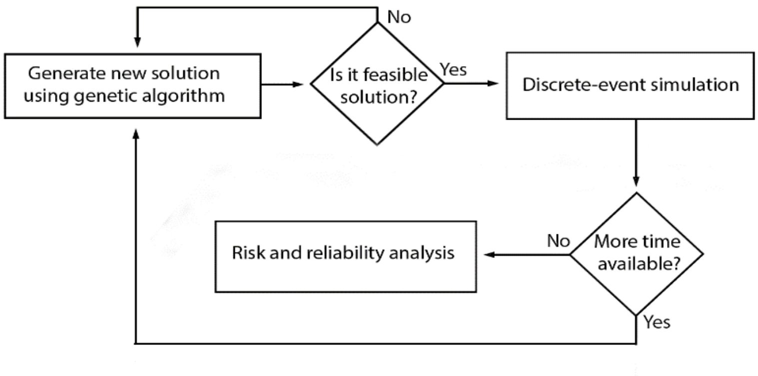


Figure 1. Methodology workflow of genetic algorithm-based simheuristics

Byrne and Hossain (2005) apply a recursive optimization–simulation approach to a production planning problem in a job shop system. The key purpose of simulation in this model is computing adjusted production capacities taking into account the delay times in the system and refining them in the analytical model. Three years later Ekren and Heragu (2008) discuss the way to optimize a single-product, two-echelon inventory system. The authors designed a simulation based on two policies and five scenarios. In the research conducted by Angelidis *et al.* (2012) the authors face scheduling problems in complex assembly lines. In particular, they consider the problem often referred to as a multi-mode, resource-constrained, multi-project scheduling problem with activity splitting. To solve this problem, they developed a simulation-driven heuristic decentralized algorithm based on selforganization.

Laroque *et al.* (2012) present a hybrid approach of a combination of particle swarm optimization and genetic algorithms as an automatic experimental design in a distributed simulation environment. These authors use a simple material flow simulation problem to evaluate the solution given by the described procedure. Almeder and Hartl (2013) tackled a scheduling problem related to a real production process in the metal industry. The model may be described as a stochastic flexible flow-shop problem with finite buffers. The authors propose a variable neighbourhood search approach in which the cost function is evaluated either by Monte Carlo simulation or by a discrete-event simulation.

Lin and Huang (2014) address the issue of automated material handling systems in a semiconductor fabrication plant. The stochastic and complex manufacturing process is represented by a simulation model, which is optimized using a particle swarm optimization metaheuristic. The algorithm is enhanced by the use of optimal computing budget allocation, which reduces the number of required simulations.

In the recent research (Juan *et al.*, 2014) authors managed to analyse the permutation flow-shop problem with stochastic times, a generalization of the well-known NP-hard permutation flow-shop problem in which the processing time of each job in each machine is a random variable under a positive probability distribution. Since uncertainty is present in most real-life processes and systems, considering random processing times represents a more realistic scenario than simply considering deterministic times. As a result, unforeseen circumstances can lead to sudden changes in the processing time of certain jobs in certain machines, which is likely to have noticeable effects on the predicted makespan, i.e., the total completion time of all jobs.

In the previous study (Jackson *et al.*, 2018) we presented a combination of discrete-event simulation and genetic algorithm to define the optimal inventory policy in stochastic multi-product inventory The proposed optimization technique is a simple to design and computationally efficient approach to find nearly-optimal inventory policy in stochastic multi-product inventory systems. Besides, the combination of discrete-event simulation and genetic algorithm provides a flexible method to solve complex problems with lack of knowledge on the structure of the objective function.

It is worth to note that the most significant drawback of such a combined approach is that the solutions are not expected to be optimal. However, real-life stochastic optimization is commonly NP-hard in nature, thus, the combination of simulation with metaheuristics seems to be a tempting alternative for practical tasks, since such an approach provides a relatively simple and flexible method to deal with complex problems in reasonable computing times.

3. Digital Twin as a Potential Augmentation

Digital Twin stands for a precise digital replica of physical objects, processes and whole systems. The digital representation provides both the elements and the dynamics of how an Internet of things device operates and lives throughout its life cycle. A digital twin continuously learns from itself, using sensor data, from human experts, such as engineers with solid industry domain knowledge and from other similar virtual environments. In various industrial sectors, Digital Twins were applied to optimize the operation of physical systems. Among successful examples is the research by Kirchhof (2016), who describes a practical case in which entire simulation models of a complex and large scale automotive flow shop production are automatically generated in order to support operational planning purposes and reduce operational logistical risks. Jain and Lechevalier (2016) describe the method for automatic generation of virtual factory models using manufacture-related configuration data. The research includes the application of simulation at multiple levels within manufacturing with extremely detailed level to discrete event simulation-based high level supply chain models. The proposed method is aimed to construct a detailed virtual factory model. Additionally, Uhlemann *et al.* (2017) present a Digital Twin of the production system within a medium-sized enterprise. The described concept contains the proposal for database structure and guidelines for the implementation in production systems at a medium-sized enterprise. Such a Digital Twin potentially allows the construction of a cyber-physical production system.

4. Deep Leaning as a Potential Augmentation

The concept of artificial intelligence has been firstly mentioned in 1943 (Warren *et al.*, 1943) and the idea of improving productivity and mining insights through data analytics and modelling is relatively old. Recently deep learning has become an active research branch of artificial intelligence for the entire product life cycle of production, planning and distribution. Conventionally deep learning is applied to problems that can not be easily formulated as an algorithm (Kriesel, 2007).

Since the universal approximation theorem proven by Cybenko (1989). states that a feed-forward network with at least a single hidden layer containing a finite number of neurons can approximate continuous functions. The theorem says that deep neural networks can represent a wide variety of functions interesting for industries. In this regard, deep learning may become an additional augmentation to the simheuristic framework. This statement is supported by several recent attempts to apply a deep neural network to solve combinatorial optimizations problems related to scheduling. Namely, the research by Rouhani *et al.* (2010) provides an artificial neural network which is able to solve the flow shop scheduling problem optimally by the accuracy rate of 90% for the 6-jobs and 5-machines flow shop scheduling problem. Moreover, the recent study by Weijia *et al.* (2017) concludes that deep reinforcement learning method has the potential to improve traditional resource allocation algorithms in a variety of complicated variations. In the provided numerical example the network outclassed classical heuristics reducing the average job slowdown by 8.57%. It is also worth to note that even much earlier Altiparmak *et al.* (2002) proposed a hybrid methodology to find a nearoptimal buffer size configuration for the asynchronous assembly systems. He proposed approach combines an artificial neural network model with simulated annealing search.

Deep learning may be incorporated into the framework of simheuristics the following way (Fig. 2). The demonstrated feedback loop suggest to develop a simulation model based on accurate representation of real industrial process. The simulation model, if required by the scale of problem, may be extended to a Digital Twin, which generates additional training data for deep neural network used to approximate optimal parameters for a real-world problem.

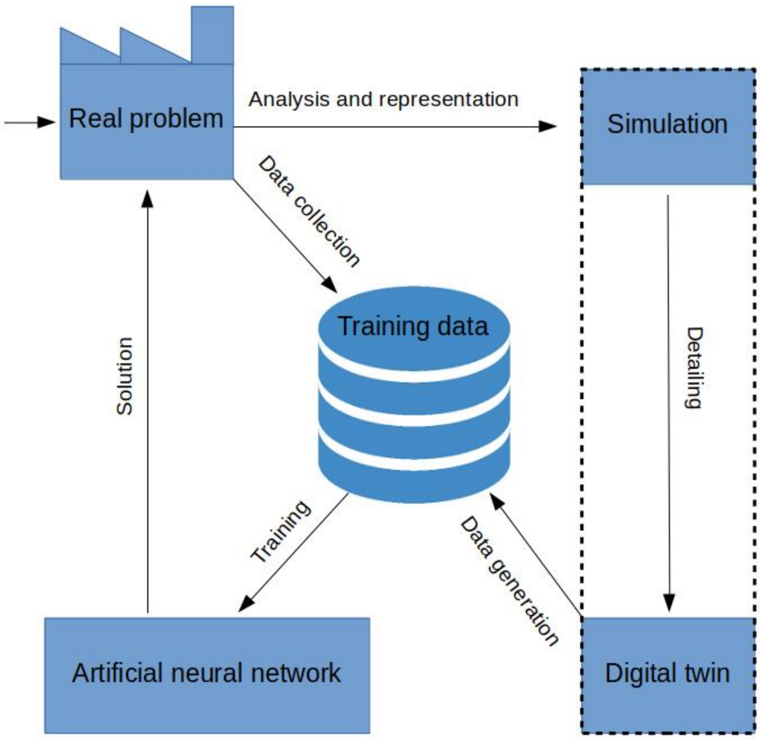


Figure 2. Augmented methodology workflow

5. Conclusions

The systems around us are quite inefficient in terms of both monetary and environmental measure. This problem is deeply rooted on the lack of tools to improve design, reliability, sustainability and operations. This paper concludes with the statement that simulation allows for extending existing and highly efficient metaheuristics to solve stochastic combinatorial optimization problems providing nearly-optimal solutions to complex real-life industrial problems in reasonable computing times.

Since with the increased integration of simulation in the product life cycle management, the requirements for simulation have changed significantly, a Digital Twin simulation paradigm along with deep learning-based artificial intelligence are required to be incorporated into simheuristic workflow. Deep learning may be naturally incorporated into the framework of simheuristics. Namely, it is suggested to develop a simulation model based on accurate representation of real industrial process. Such a simulation model, if required by the scale of problem, may be extended to a Digital Twin, which generates additional training data for deep neural network used to approximate optimal parameters for a real-world problem.

In future research we expect to provide a simulation-driven AI solution for long-standing stochastic inventory optimization problem.

Acknowledgements

This work has been supported by the ALLIANCE project (http://alliance-project.eu/) and has been funded within the European Commission's H2020 Programme under con-tract number 692426. This paper expresses the opinions of the authors and not necessarily those of the European Commission. The European Commission is not liable for any use that may be made of the information contained in this paper.

References

1. Almeder, C. and Hartl, R.F. (2013) A metaheuristic optimization approach for a real-world stochastic flexible flow shop problem with limited buffer. *International Journal of Production Economics*, 145(1), 88-95.
2. Altiparmak F, Dengiz B, Bulgak AA. (2002) Optimization of buffer sizes in assembly systems using intelligent techniques. In: *Proceedings of the 2002 conference on winter simulation conference*. 1157–1162.
3. Angelidis, E., Bohn, D. and Rose, O. (2012) December. A simulation-based optimization heuristic using self-organization for complex assembly lines. In: *Proceedings of the Winter Simulation Conference*, 276. Winter Simulation Conference.
4. Bianchi, L., Dorigo, M., Gambardella, L.M. and Gutjahr, W.J. (2009) A survey on metaheuristics for stochastic combinatorial optimization. *Natural Computing*, 8(2), 239-287.
5. Bullers, W.I., Nof, S.Y. and Whinston, A.B. (1980) Artificial intelligence in manufacturing planning and control. *AIIE transactions*, 12(4), 351-363.
6. Byrne, M.D. and Hossain, M.M. (2005) Production planning: An improved hybrid approach. *International Journal of Production Economics*, 93, 225-229.
7. Chen, W., Xu, Y. and Wu, X. (2017) *Deep Reinforcement Learning for Multi-Resource Multi-Machine Job Scheduling*. arXiv preprint arXiv:1711.07440.
8. Cybenko, G. (1989) Approximation by superpositions of a sigmoidal function. *Mathematics of control, signals and systems*, 2(4), 303-314.
9. Dengiz B, Alabas C. (2000) Simulation optimization using tabu search. In: *Proceedings of the 2000 winter simulation conference*, p. 805–810.
10. Ekren, B.Y. and Heragu, S.S. (2008) December. Simulation based optimization of multi-location transshipment problem with capacitated transportation. In: *Proceedings of the 40th Conference on Winter Simulation*, 2632-2638. Winter Simulation Conference.
11. Goossens, P. (2017) Industry 4.0 and the Power of the Digital Twin. *Retrieved*, 5(3), p.2017.
12. Jain, S. and Lechevalier, D. (2016) December. Standards based generation of a virtual factory model. In: *Proceedings of the 2016 Winter Simulation Conference*, 2762–2773. IEEE Press.
13. Jackson, I., Tolujevs, J. and Reggelin, T. (2018) The Combination of Discrete-Event Simulation and Genetic Algorithm for Solving the Stochastic Multi-Product Inventory Optimization Problem. *Transport and Telecommunication Journal*, 19(3), 233–243.
14. Juan, A.A., Faulin, J., Grasman, S.E., Rabe, M. and Figueria, G. (2015) A review of simheuristics: Extending metaheuristics to deal with stochastic combinatorial optimization problems. *Operations Research Perspective*, 2, 62–72. DOI:10.1016/j.orp.2015.03.001.
15. Juan, A.A., Grasman, S.E., Caceres-Cruz, J. and Bektaş, T. (2014) A simheuristic algorithm for the single-period stochastic inventory-routing problem with stock-outs. *Simulation Modelling Practice and Theory*, 46, 40–52. DOI:10.1016/j.simpat.2013.11.008.
16. Juan, A.A., Barrios, B.B., Vallada, E., Riera, D. and Jorba, J. (2014) A simheuristic algorithm for solving the permutation flow shop problem with stochastic processing times. *Simulation Modelling Practice and Theory*, 46, pp.101-117.

17. Jung, J.Y., Blau, G., Pekny, J.F., Reklaitis, G.V. and Eversdyk, D. (2004) A simulation based optimization approach to supply chain management under demand uncertainty. *Computers & chemical engineering*, 28(10), pp.2087-2106.
18. Jung, J.Y., Blau, G., Pekny, J.F., Reklaitis, G.V. and Eversdyk, D. (2008) Integrated safety stock management for multi-stage supply chains under production capacity constraints. *Computers & Chemical Engineering,* 32(11), pp.2570-2581.
19. Kirchhof, P. (2016) Automatically generating flow shop simulation models from SAP data. In: *Proceedings of the 2016 Winter Simulation Conference* (pp. 3588-3589).
20. Kriesel, D. (2007) A Brief Introduction to Neural Networks. 2007.
21. Laroque, C., Klaas, A., Fischer, J.H. and Kuntze, M. (2012) Fast converging, automated experiment runs for material flow simulations using distributed computing and combined metaheuristics. In: *Proceedings of the Winter Simulation Conference* (p. 255). Winter Simulation Conference.
22. Lin, J.T. and Huang, C.J. (2014) A simulation-based optimization approach for a semiconductor photobay with automated material handling system. *Simulation Modelling Practice and Theory*, 46, pp.76-100.
23. Pidd, M. (1998) *Computer simulation in management science*. ISBN:0471979317.
24. Rodic, B. (2017) Industry 4.0 and the new simulation modelling paradigm. *Organizacija*, 50(3), pp.193-207.
25. Rouhani, S., Fathian, M., Jafari, M. and Akhavan, P. (2010) Solving the Problem of Flow Shop Scheduling by Neural Network Approach. In: *International Conference on Networked Digital Technologies*, (pp. 172-183). Springer, Berlin, Heidelberg.
26. Subramanian, D., Pekny, J. F. and Gintaras, V. R. (2000) A simulation—optimization framework for addressing combinatorial and stochastic aspects of an R&D pipeline management problem. *Computers & Chemical Engineering*, 24(2-7), 1005–1011.
27. Subramaniam, G. and Gosavi, A. (2004) Simulation-based optimization for material dispatching in a retailer network. In: *Proceedings of the 36th conference on Winter simulation*, (pp. 1412-1417). Winter Simulation Conference.
28. Swisher, J.R., Hyden, P.D., Jacobson, S.H. and Schruben, L.W. (2000) A survey of simulation optimization techniques and procedures. In: *Simulation Conference, 2000. Proceedings.* Winter (Vol. 1, pp. 119-128). IEEE.
29. Truong, T.H. and Azadivar, F. (2003) Simulation optimization in manufacturing analysis: simulation based optimization for supply chain configuration design. In: *Proceedings of the 35th conference on Winter simulation: driving innovation*, (pp. 1268-1275). Winter Simulation Conference.
30. Uhlemann, T.H.J., Lehmann, C. and Steinhilper, R. (2017) The digital twin: Realizing the cyber-physical production system for industry 4.0. *Procedia Cirp*, 61, pp.335-340.
31. Warren, S. McCulloch and Walter H. Pitts (1943) A Logical Calculus of the Ideas Immanent in Nervous Activity, *Bulletin of Mathematical Biophysics*, 5:115-133.

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 37-45
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

3D RECONSTRUCTION OF HUMAN'S FACE IN PERSON'S IDENTIFICATION PROBLEM FROM VIDEO STREAM DATA

Fyodor Panchuk, Alexander Grakovski

Transport and Telecommunication Institute, Riga, Latvia
avg@tsi.lv

The problem of a human's face recognition on base of photo or video images obtained under different angles of vision is considered. To solve such a problem, it can be used the reconstruction of a three-dimensional (3D) face model constructed in automatic mode using the 'Shape from Stereo' (SFS) approach. Usually the ordinary photos are used as the models, but the following problem arises in this case: the photo used as the sample for identifying a human face on photo, is sensitive to the existent head's position in space of this photo. Sometimes there are cases when the human's face cannot be automatically identified in the photo, because the face on the photo is rotated at some angles, where it is impossible to compare it with the reference photo. A method for evaluating the quality of the obtained model is proposed, based on a comparison of the synthesized plane images of a person with the original photographs by the criterion of least squares of errors.

Keywords. Transport security, Computer vision, face recognition, optical flow, epipolar geometry, stereo correspondence, 3D reconstruction

1 Introduction

The problem of automatic identification of a person by photo or video data is quite actual for computer vision systems used to provide passenger and personnel access control, airport security, public buildings, critical infrastructure facilities, etc., that is reflected in a large number of scientific researches, projects and publications (Kurmi and Baghel, 2014; Biswas *et al*., 2013; Rani and Sharma, 2013; Jindal and Kumar, 2013). Two models, as a rule, are used for a human's face identification:

- reference model contains the face where the association with certain person is already known (the passport photo of this person can be considered);
- digital image or photo where a human's face can be detected and its parameters can be compared with the parameters of reference model when performing identification.

Usually simple photos are used as the models, but the following problem arises in this case: the photo used as the sample for identifying a human face on photo, is sensitive to the existent head's position in space of this photo. Sometimes there are cases when the human's face cannot be automatically identified in the photo, because the face on the photo is rotated at some angles, where it is impossible to compare it with the reference photo.

The problem can be solved with the use of a three-dimensional (3D) model of human's head surface (Rani and Sharma, 2013). The shortcomings of different methods using this approach were found, and the way of improvement based on video stream application instead of a pair of photographs, was proposed. Comparison of linked stereo pairs is made by usual SFS approach for both basic and improved version of method. 3D model contains much more information than an ordinary photo, and its view (position in space) no longer affects the quality of recognition. However, a lot of resources can be required to create a 3D human's head model manually for storement in database, so the automation of this process seems to be desirable.

The automatization of the human face 3D model reconstruction is a relevant problem, that can be built using different techniques: laser scanning (Heritage and Large, 2009), face model reconstruction from shadows with the use of '*Structure from shading*' algorithm (Prados and

Faugeras, 2006), reconstruction of 3D head model from multiple photos (Medioni *et al*., 2000). Well-known SFS (Shape from Stereo) reconstruction algorithm was examined here, and the idea of modifying this algorithm was discussed. Additionally, the method for evaluating the quality of 3D model, based on a comparison of the synthesized plane images of a person with the original photographs by the criterion of least squares of errors, is proposed.

The paper is organized as follows: Section 2 presents related work and general overview of SFS algorithm. Section 3 describes the modification of '*Shape from Stereo'* algorithm. Section 4 illustrates the results of the modified SFS algorithm. And, finally, Section 5 includes the conclusions and future work directions.

2 3D Human's Face Model Reconstruction and Related Work

Methods that perform reconstruction of 3D models can be divided into three groups: reconstruction from shadows (Prados and Faugeras, 2006); reconstruction with the use of special devices (Heritage and Large, 2009); reconstruction from multiple photos (Medioni *et al*., 2000) (see Figure 1).

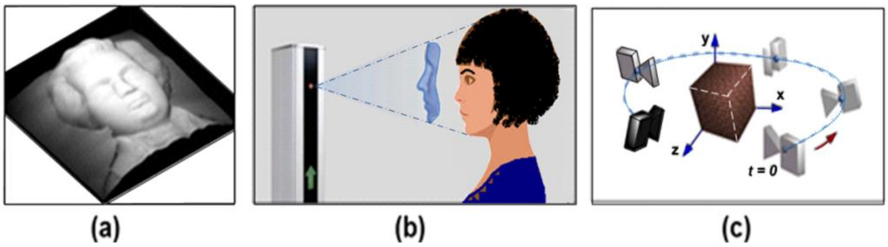


Figure 1. 3D face reconstruction techniques: (a) reconstruction by shadows, (b) laser scanning, and (c) reconstruction from multiple photos

In the process of reconstruction by shadows only one photo is used. The number and position of light sources is determined and 3D reconstruction is performed. Such methods group requires only one photo for analysis (Prados and Faugeras, 2006), and in case of some defects on it, the resulting model obtains this distortions too. Second method group is using special devices for model reconstruction, and usually the price of such devices is quite high (Heritage and Large, 2009). Thus, looks like the third group of reconstruction methods is the most acceptable (Medioni *et al*., 2000), because it does not require expensive devices for reconstruction, and several photos are used as source for face 3D reconstruction. It provides certain reliability, since the defects on one photo do not affect the overall result significantly.

Among the methods of this group the SFS (*Shape from Stereo*) algorithm was examined especially. It performs 3D reconstruction on base of the photo stereo pair (Medioni *et al*., 2000). Although the SFS approach does not imply any single reconstruction algorithm, nevertheless, the most common steps of reconstruction are the following: search for singular points in both photos; comparison of points among themselves; filtering incorrectly mapped points; determining the position of cameras in space; and, finally, calculation of three-dimensional coordinates of mapped points.

2.1. Feature Detection

At the stage of singular points (features) detecting, those detectors are used for searching of pixels (or pixel groups), that significantly differs from nearest neighbour pixels (Harris and Stephens, 1988; Shi and Tomasi, 1994; Bay *et al*., 2008).

Harris Detector (Harris and Stephens, 1988)

It uses a small neighbourhood area (window) around each pixel and tries to determine the *'cornerness'* of the pixel by estimating the changes in pixel intensity in this window when it moves in different directions for a short distance. To estimate the changes in intensity, the sum of the squares of the intensity differences between an original and shifted pixel is used. For each pixel in the window the weight function is calculated. Usually the Gaussian function can be applied as the function of weight (1):

$$w(x, y) = exp\left(-\frac{x^2+y^2}{2\sigma^2}\right). \quad (1)$$

Finally, by the approximation of Taylor's series, the image processing allows to calculation of autocorrelation matrix M:

$$M(x, y) = \sum_{u,v \in W} W(u, v) \begin{bmatrix} \left(\frac{\partial I}{\partial x}\right)^2 & \frac{\partial I}{\partial x} * \frac{\partial I}{\partial y} \\ \frac{\partial I}{\partial y} * \frac{\partial I}{\partial x} & \left(\frac{\partial I}{\partial y}\right)^2 \end{bmatrix}. \quad (2)$$

To evaluate the 'cornerness' of examined area equation (3) is applied, where λ_1, λ_2 are the eigenvalues of autocorrelation matrix M respectively (2), and $k \in [0.04 \ldots 0.06]$.

$$R = \lambda_1 * \lambda_2 - k\,(\lambda_1 + \lambda_2)^2. \quad (3)$$

Harris detector has the main advantage: insensitiveness to the image rotation angle. However, it is sensitive to the changes of scale that is significant disadvantage of this method (Harris and Stephens, 1988).

Shi-Tomasi Detector (Shi and Tomasi, 1994)

This detector can be considered as an advanced Harris detector (Harris and Stephens, 1988) that uses more stable function for "cornerness" area evaluation, as specified in expression (4), and works well when tracking corners as a large scale changes in the image area.

$$R = \min(\lambda_1, \lambda_2). \quad (4)$$

SURF Detector (Bay et al., 2008)

Unlike previous methods, the SURF-detector (*Speeded-Up Robust Features*) remembers the descriptor of each found singular point. It calculates the Hessian (determinant of the Hesse matrix) for each point during the process of features detection and compares it with the threshold value.

The expression (5) reflects the Hessian calculation rule, where D_{xx}, D_{xy} and D_{yy} are the convolutions of filters (see Figure 2):

$$\mathrm{Det}(H) = D_{xx}D_{yy} - \left(0.9 * D_{xy}\right)^2. \quad (5)$$

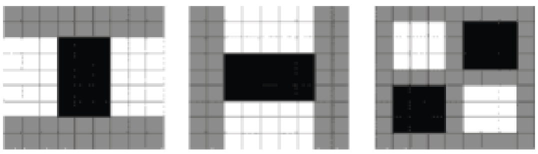


Figure 2. Filters used for Hessian calculation (Bay *et al.*, 2008)

2.2. Detected Features (Peculiarities) Matching

K-nearest Neighbour Method

This method is a special case of the method for classification of *K*-nearest neighbours (Brett, 2013). Its perculiarity lies in the fact that two sets of points are fed into the input, one of them is considered as a training point set and the second is an evaluated point set. Each point of the training set is considered as a separate class.

For the point of evaluated set the K-nearest neighbours are determined. It is supposed that the point has the same class as the point with the most similar descriptor (some information about neighbours is assumed as the descriptor). Thus, it turns out that the pair of points having the same class in the training and evaluated sets corresponds to the same point of the three-dimensional object (Brett, 2013).

Optical Flow

The idea of this algorithm formulates as follows: the optical flow is calculated as tracking the displacement of a particular pixel on two adjacent frames (Wedel and Cremers, 2011). Determination of optical flow can be summarized to solving one equation with several variables that has an infinite set of solutions in the general case.

The algorithm suggests determining the intensity not for each pixel separately but taking into account the neighbourhoods around it. The calculation of the optical flow value is needs to solve the system of equations by the Least Square method (LSQ), reducing the number of possible solutions (Wedel and Cremers, 2011).

This approach shows good results on practice, although it does not always ensure the existence of a single solution. In cases with repeatable elements on the image such uncertainty exists, and it is called by '*aperture problem*' (Wedel and Cremers, 2011).

2.3. Filtration of Incorrectly Matched Pairs of Pixels

In presence of two images where one and the same object of the real world is imaged, the centres of cameras location, and specific points of the three-dimensional object, form together an *epipolar plane*. The intersection of this plane with the image plane forms an *epipolar line*. The intersection of a straight line connecting the centres of the cameras with the image plane forms the point called by *epipole* (see Figure 3). The aggregation of all elements forms the *epipolar geometry* of the object (Hartley and Zisserman, 2004).

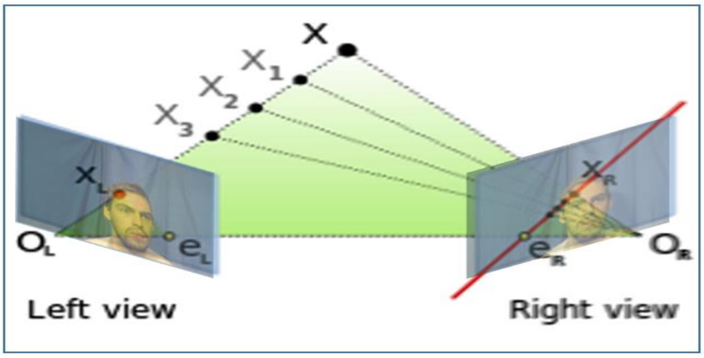


Figure 3. Epipolar geometry of the image points

The idea of *epipolar filtering* (Hartley and Zisserman, 2004) consists of the follows: in the case when the point was incorrectly mapped, the position of the image planes for it will look different, and therefore, the epipoles will be shifted, that can be used as the indicator of fact of false correspondence between the points.

Epipolar geometry can be algebraically represented by the *fundamental matrix* (Hartley and Zisserman, 2004), it is the second rank matrix, size of 3×3. The condition for epipolar geometry satisfying for a pair of points can be described by the equation (6):

$$p^T * F * p' = 0, \tag{6}$$

where $p(x, y)$ is coordinate vector of the point on the first image, $p'(x, y)$ is coordinate vector of the point on the second image, and F is the fundamental matrix. It can be calculated on the base of intrinsic camera parameters, or with the use of eight-point algorithm (Solem, 2012) for detected sets of stereo pairs. An objective function for optimisation describes by the expression (7):

$$\sum_{i=1}^{8}(p_i^T F p'_i)^2 \to min, \qquad F = \begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix}, \tag{7}$$

$$\begin{bmatrix} x'_1x_1 & x'_1y_1 & x'_1 & y'_1x_1 & y'_1y_1 & y'_1 & x_1 & y_1 & 1 \\ x'_2x_2 & x'_2y_2 & x'_2 & y'_2x_2 & y'_2y_2 & y'_2 & x_2 & y_2 & 1 \\ x'_3x_3 & x'_3y_3 & x'_3 & y'_3x_3 & y'_3y_3 & y'_3 & x_3 & y_3 & 1 \\ x'_4x_4 & x'_4y_4 & x'_4 & y'_4x_4 & y'_4y_4 & y'_4 & x_4 & y_4 & 1 \\ x'_5x_5 & x'_5y_5 & x'_5 & y'_5x_5 & y'_5y_5 & y'_5 & x_5 & y_5 & 1 \\ x'_6x_6 & x'_6y_6 & x'_6 & y'_6x_6 & y'_6y_6 & y'_6 & x_6 & y_6 & 1 \\ x'_7x_7 & x'_7y_7 & x'_7 & y'_7x_7 & y'_7y_7 & y'_7 & x_7 & y_7 & 1 \\ x'_8x_8 & x'_8y_8 & x'_8 & y'_8x_8 & y'_8y_8 & y'_8 & x_8 & y_8 & 1 \end{bmatrix} * \begin{bmatrix} F_{11} \\ F_{12} \\ F_{13} \\ F_{21} \\ F_{22} \\ F_{23} \\ F_{31} \\ F_{32} \\ F_{33} \end{bmatrix} = 0, \tag{8}$$

where p_i is an i-th point's coordinate vector of the left image, p'_i is the i-th point's coordinate vector of the right image (see Fig. 3.). The system, described by expression (8), provides the selection of the fundamental matrix F so, that all the singular points p_i and p'_i of both images maximally satisfy the condition of correspondence of epipolar geometry (6).

2.4. Determining the Position of Cameras in Space

Each camera can be described by intrinsic and extrinsic parameters (9), where K is the matrix of intrinsic camera parameters: f is the focal length, γ is the aspect ratio, s is the skew, and (x_C, y_C) is the orthogonal projection of the focal point onto the image plane (for most cameras $s = 0$ and $\gamma \approx 1$ and the focal point is located close to the centre of the image) (Medioni and Kang, 2004).

$$K = \begin{bmatrix} \gamma f & sf & x_c \\ 0 & f & y_c \\ 0 & 0 & 1 \end{bmatrix}, \; R = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix}, \; t = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}. \tag{9}$$

Extrinsic parameters are: R is the rotation matrix, and t is the vector of translation. '*Shape from Stereo'* approach requires the intrinsic camera parameters to be known. It can be previously obtained by cameras calibration. Fundamental matrix F (8) together with internal parameters of both cameras K and K' (9) allows calculating the *essential matrix E* with the 3×3 size (10):

$$E = K^T F K'. \tag{10}$$

Essential matrix can be also calculated using the translation matrix $[t]_x$ of translation vector t from (9) containing the required external parameters of the camera (11):

$$E = R \cdot [t]_x, \; [t]_x = \begin{bmatrix} 0 & -t_z & t_y \\ t_z & 0 & -t_x \\ -t_y & t_x & 0 \end{bmatrix}. \tag{11}$$

It is possible to perform singular value decomposition (SVD) of essential matrix E, and to find of the most appropriated of possible combinations of parameters R and t that determines the correct alignment of the cameras by technique described in (Hartley and Zisserman, 2004).

2.5. 3D Coordinate Calculation of Points

The calculation of the three-dimensional coordinates of the selected point pairs is called the triangulation of points (Zhang, 1998). Ideally, if the point which 3D coordinates we are trying to retrieve is lying on camera projection lines intersection and all camera parameters are known, then it is possible to calculate the 3D coordinates of the points. However the noise, as well as the inaccuracies in the calibration of cameras and points matching lead to the projection lines of cameras to this point contain the error and do not intersect. Let to decrease the error, the triangulation can be applied (Zhang, 1998):

$$\left[(p_x - up_z)\ \ (p_y - vp_z)\ \ (p'_x - u'p'_z)\ \ (p'_y - v'p'_z)\right]^T [x\ \ y\ \ z\ \ t]^T = 0.. \tag{12}$$

The algorithm for linear triangulation can be described in terms of estimation of coordinate's vector $[x\ y\ z\ t]$ in equation (12), where p_x, p_y, p_z are the vectors of projection matrix $P = K \cdot C$ on axes x, y, z respectively, pairs (u, v) and (u', v') are the points coordinates on both of images, and $C = [R|t]$ is the concatenation of rotation matrix R and translations vector t from (9). It is possible to calculate it by OpenCV built-in functions application (Camera Calibration and 3D Reconstruction, 2018).

3 Modification of the SFS (Shape from Stereo) Algorithm

The SFS method has one weakness: the number of points in the final model directly depends on the number of points found initially. The determination of number of points in resulting model can be described by expression (13), where n is the resulting model point count, f_1 and f_1 are the features found on both of the photo respectively, f_u is unmatched point pairs, and f_f is filtered point pairs:

$$n = \max(f_1, f_2) - (f_u + f_f). \tag{13}$$

Therefore, it is necessary to provide the largest number of initially detected features, in order to improve the model quality. For determination the detector who produces the best results, several experiments were performed and an empirical evaluation was made, examining the number of found features on the photo (see Figure 4).

Figure 4. Real result of detector functioning: (a) original photo, (b) by Harris detector (Harris and Stephens, 1988), (c) by Shi-Tomasi detector (1994), (d) by SURF detector (Bay *et al.*, 2008)

By numerical experiment results (Figure 4), the greatest number of features was found by the Shi-Tomashi algorithm (Shi and Tomasi, 1994), but it is the fact that none of the detectors provides the number of singular points sufficient for a three-dimensional face reconstruction.

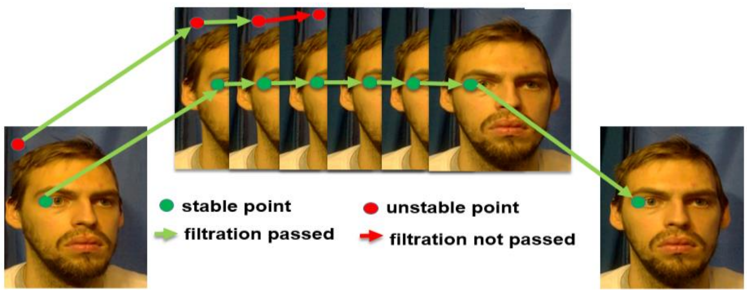


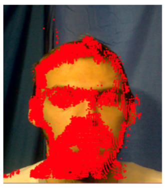
Figure 5. Intermediate frames used to increase the number of mapped points and filtering of unstable points

The idea of changing this step of the method is as follows: first we need to determine the significant number of points that cover the photo evenly, and then in a special way remove all unstable points from this set. For this purpose, the video stream can be used as input data instead of two photographs in the original SFS method (Medioni *et al*., 2000).

The first and last frames of the video stream will act as a stereopair, and the intermediate frames can be used to match the largest number of points in the photograph (see Figure 5) while simultaneously identifying unstable points. Having determined the correspondence of a certain point on the next frame, it is possible to refind the correspondence on earlier frame, etc. After the distance between the starting and ending position of the point on the frame was evaluated, and if this distance is bigger than some specified threshold value, then this point can be considered unstable (see Figure 6).

Figure 6. Unstable point filtration via optical flow

On post-processing stage the 3D model can be improved by artificial filling the empty areas between the points on base of bilinear or bicubic interpolation (Wang and Yang, 2008).



(a)

	Stereopair 1	Stereopair 2	Stereopair 3	Average
Shi-Tomasi	4580	4312	4210	4367.3
Harris	110	174	90	124.7
SURF	592	700	621	637.7
Videostream with filtration	25044	23725	21860	23543

(b)

Figure 7. Result of improved point matching: (a) set of matched points on base of videostream data, (b) table with the number of points found by existing detectors in comparison with proposed approach

The comparison between the results of another detectors and proposed approach (see Figure 7) demonstrates that videostream data processing produces significant increase the quantity of correctly matched points that are enough for 3D reconstruction.

4 Results and Discussion

As the result of proposed algorithm, three-dimensional clouds of points were obtained, as well as a set of triangular faces that made it possible to display the resulting cloud as a monolithic bilinearly interpolated three-dimensional (3D) model (see Figure 8).

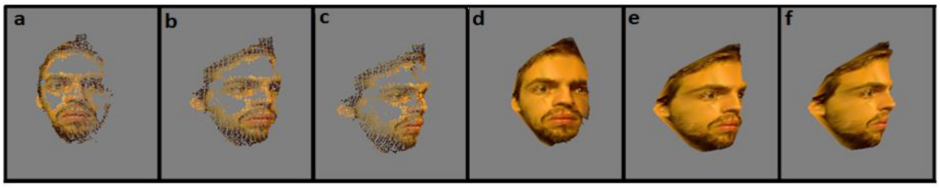


Figure 8. Synthesized image of human’s face under different angles: (a-c) cloud of correctly matched singular points, (d-f) the same after bilinear interpolation of internal spaces Wang and Yang, 2008)

Evaluating the quality of 3D reconstruction the comparison between original photography image and synthesized flat face image under the same angle was made by Least Square (LSQ) criterion where the errors were calculated as the differences of intensity values of the pixels (see Figure 9).

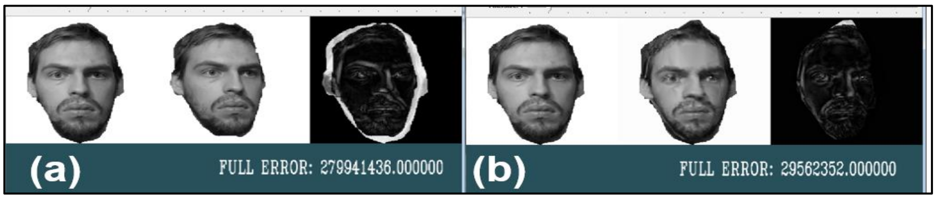


Figure 9. Image comparison: (a) errors between source stereo pair, (b) error between source image and flat projection of correctly rotated 3D model view

The results of the evaluation of the 3D model are presented in Table 1. As it turned out, using the projection of the obtained model for comparison with one photograph, it is possible to achieve approximately a tenfold decrease in the error.

Table 1. Comparison of synthesized flat face images with the original photographs by LSQ criteria

Compared frames	Window size	Calculated error
First photo and synthesized image	1x1	$1.769 \cdot 10^7$
Second photo and synthesized image	1x1	$2.956 \cdot 10^7$
First photo and second photo	1x1	$2.799 \cdot 10^8$
First photo and synthesized image	5x5	$1.199 \cdot 10^7$
Second photo and synthesized image	5x5	$1.630 \cdot 10^7$
First photo and second photo	5x5	$2.328 \cdot 10^8$

5 Conclusions and Future Research

When studying the general method "Form from stereo" (SFS) of 3D reconstruction algorithm for two photoimages in face recognition problem, main drawback of SFS was revealed: it creates insufficient number of special points that isn't enough for 3D reconstruction. Modified method based on videostream data was proposed. The analysis of its effectiveness showed that modified method really increases the number of points by dozens of times in comparison with existing methods. On base of improved algorithm the 3D reconstruction of the human's face was created. The evaluation of the synthesized images pixel intensity errors by LSQ criterion demonstrates its applicability for face recognition tasks. Unfortunately, obtained 3D model demonstrates some limitations on the angle of rotation, since it is possible to restore only that area of the human's head that is displayed on all frames of initial videostream data.

The approach '*Structure from motion*' (SFM) for 3D-reconstruction (Shoenberger and Frahm, 2016) is planned to be analysed in future work. This method allows receiving an unlimited head rotation angle, and also performs automatic camera calibration (Armstrong, 1996). Since this approach is associated with singular points detectors usage for 3D reconstruction too, proposed method also can be applied.

Acknowledgements

This research was supported by special grant of "X-Infotech" Ltd. Co (Latvia) in 2017.

References

1. Armstrong, M.A. (1996) *Self-Calibration from Image Sequences*. PhD Theses, University of Oxford, Dept. of Engineering Science, Michaelmas Term
2. Bay H., Ess A., Gool L.V. (2008) SURF: speed up robust features. *Computer Vision and Image Understanding (CVIU)*, Vol.110, No.3, pp. 346-359
3. Biswas, S., Aggarwal, G., Flynn, P.J., and Bowyer, K.W. (2013) Pose-robust recognition of low-resolution face images. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Volume 35, No. 12, pp. 3037–3049.
4. Brett, L. (2013) *Machine learning with R*. 1st Ed., Pact. Publishing, London.

5. Camera Calibration and 3D Reconstruction. OpenCV 3.0.0-dev documentation. Revisited June 30, 2018 from: - https://docs.opencv.org/3.0-beta/modules/calib3d/doc/camera_calibration_and_3d_reconstruction.html
6. Harris, Ch. and Stephens, M. (1988) *A combined corner and edge detector*. Revisited March 21, 2018 from: http://www.bmva.org/bmvc/1988/avc-88-023.pdf
7. Hartley R., and Zisserman A. (2004) *Multiple View Geometry in Computer Vision* (Second Edition). Cambridge University Press.
8. Heritage, G.L., Large, A.R.G. (2009) *Laser Scanning for the Environmental Sciences*. John Wiley & Sons, 288 p.
9. Jindal, N. and Kumar, V. (2013) Enhanced face recognition algorithm using pca with artificial neural networks. *International Journal of Advanced Research in Computer Science and Software Engineering*, Volume 3, No. 6, pp. 864-872.
10. Kurmi, U., Baghel, R. (2014) Study of Different Face Recognition Algorithms and Challenges, *IJER*, Volume 3, No.2, pp. 112-115.
11. Medioni G., Kang, S. B. (2004) *Emerging Topics in Computer Vision*. Prentice Hall, 667 p.
12. Medioni, G., Mi-Suen Lee, Chi-Keung Tang (2000) *A Computational Framework for Segmentation and Grouping*,1st Edition, pp. 183-198.
13. Prados, E. and Faugeras, O. (2006) *Shape from shading. Handbook of Mathematical Models in Computer Vision*, N. Paragios, Y. Chen, and O. Faugeras, Eds., Springer US, pp. 375–388.
14. Rani, S.K., Sharma, T.C. (2013) Face Recognition office security system using Lab View 8.6. *IJECIERD*, Volume 3, No.2, pp. 195-200.
15. Shi, J. and Tomasi, C. (1994) Good Features to Track, In: *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR'94)*, June 1994, Seattle, USA, pp. 593-600.
16. Shoenberger J.L., Frahm J.-M. (2016) Structure-from-Motion. *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, 2016, pp. 4104-4113. Revisited March 21, 2018 from: https://demuc.de/papers/schoenberger2016sfm.pdf
17. Solem, J.E. (2012) *Programming Computer Vision with Python*. O'Reilly Media, 264 p.
18. Wang Sen, Yang Kejian (2008) An image scaling algorithm based on bilinear interpolation with VC++. *Journal of Techniques of Automation & Applications*, Volume 27, No. 7, pp. 44-45.
19. Wedel, A., and Cremers D. (2011) *Stereo Scene Flow for 3D Motion Analysis*. Springer-Verlag.
20. Zhang, Zh. (1998) Determining the Epipolar Geometry and its Uncertainty: A Review. *International Journal of Computer Vision*, Volume 27, No 2, pp. 161-195.

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 46-51
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

MULTI-LAYERED APPROACH TO THE UAV COLLISION AVOIDANCE SYSTEM

Dmitrijs Lancovs

Transport and Telecommunication Institute,
Riga, Latvia, Lomonosova 1, LV-1019

There is a gap between commercial unmanned aerial vehicles capability and demand in the field of autonomous flight. One of the problems is collision avoidance, especially considering smaller moving obstacles such as other craft and birds.

While there has been some research in the field of sensors and sensor fusion, it is mostly done around a premise that a fixed hardware configuration is used.

Future-proof solutions should instead focus on a more universal approach, while retaining sensor specifics in its profile, and should provide a unified source of data for the decision-making process.

The proposed system is built around a classic three layer model with data (sensor) fusion, feature fusion and decision making level. However, sensors provide contact parameters and parameter measurement errors, and these errors are then used during fusion and are retained at feature level.

This allows performing fusion between different kinds of sensors without having to implement very specific algorithms in each case and without losing any measured parameters.

The end result is an algorithm for data level fusion, which provides the necessary information to perform feature level fusion and decision-making during flight.

Keywords: Unmanned Aerial Vehicles, Unregulated Airspace, Sensors, Decision Support, Collision Avoidance System

1. Background

Unmanned aerial vehicle (UAV) technology is rapidly advancing, with multitude of commercial applications. However, beyond visual line of sight (BVLOS) flights remain off the table; in no small part due to lack of reliable collision avoidance mechanisms.

Although range requirements for such system were established (Lancovs, 2017), it became evident that there is a wide variety of obstacles threatening UAV navigation, and the problem cannot be solved by a single cooperative solution.

Instead, a system that accepts input from multiple sources, including self-diagnostics, and integrates them into a single "map" would be preferable. This "map" is then used by the autopilot for decision-making.

While some information sources include preloaded navigation data (terrain, buildings), others may be sensors used to identify both stationary and mobile obstacles. A three level approach has been commonly used for many years in such scenarios (Pohl and Van Genderen, 1998; Bhure and Kalyanasundaram, 2016), with transition from data level fusion to feature level, and then to decision level.

Since in this case decision-making is left to the autopilot and includes more factors than just the environment, it is necessary to provide a single source of decision support for the autopilot from multiple sources of data. Therefore, all the information must be presented spatially, ranging from moving and stationary obstacles, no-fly zones, to reachable areas based on remaining fuel and other self-diagnostic data.

Data level fusion is a problematic area even when dealing with homogenous sensors. In this case, a heterogeneous set may be employed, and each sensor has its own characteristics, defining its capabilities. Sensors have different reliability at different ranges and angles, and even weather conditions. Integrating data from such potentially unreliable sources is one of the problems to be solved.

A multi-layer approach is presented, tailored specifically for a UAV collision avoidance decision making support, based around the idea of using sensor uncertainty as an additional information source rather than a limitation. This approach retains the classic three levels of fusion mentioned above and may include another, lower level as needed.

2. The System

The system presented here is tasked with presenting the decision making component with the necessary data to perform its duty in deciding whether to continue with the present course or to alter it in some way. It should also provide the data needed to build a new course if such alterations are in order. Therefore a complete obstacle map is to be provided for in-flight route planning, which is essentially the world view available to the decision maker.

Decision making itself is outside the scope of this article, but key requirements for it are a deterministic, dynamic three-dimensional representation of obstacles, aggregated from pre-stored data, detections from sensors and data from other information sources, such as UAV transponders if any cooperative system is used to augment obstacle data acquisition. Achieving such detailed representation places requirements on lower layers of the system.

Flight plan	Waypoints	Location Flight speed
Decision making	Observe and alter flight plan as needed	
Map (updated representation of current world view)	List of all features	Location Shape *Course* *Speed*
Feature fusion	Merge detected and known obstacles	
Features (aggregated contacts)	List of known features List of detected features	Location Shape *Profile*
Contact fusion	Identify and merge sensor contacts into obstacles	
Data (sensor contacts)	List of contacts	Location Shape *Profile*

Figure 1. Layers of the system

As can be seen in the Figure 1, there are three processes and four artefacts. The bottom layer transforms sensor contacts into "features" (obstacles), aggregated entities that have their attributes from one or several merged contacts. Attributes need to include location and other relevant data for autopilot to base decisions on in higher layers, but may also include additional parameters used for fusion purposes only.

Contact fusion implies finding which contacts from various sensors represent the same physical world objects (obstacle), which is the purpose of this paper.

Feature fusion is another process that has to be done in order to update the current world view, incorporating new features into it and updating existing features if matched against new ones. It may be performed separately or as part of extended Contact fusion.

After the map is updated, the decision maker evaluates current course and flight parameters based on this data and either proceeds to continue the course or performs route planning to compensate for obstacles in or threatening to enter its current flight path.

Each step is performed periodically, and this time period is called a processing frame. There may be different processing frame durations at each level. The amount of processing frames per second may be limited by computing power, but is no higher than the update frequency of the fastest updating sensor.

3. Data Layer

3.1. Sensor uncertainty

Sensors are physical objects that are prone to measurement errors. Different sensors have different errors, and the same sensor will have different errors of measurement at different range and bearing to the observed object.

The parameters of a contact a sensor can measure can be represented as a vector

$$P=(P_1, \dots P_n), \tag{3}$$

where n is the number of characteristics it can measure. For example, a sonar may be able to measure range and nothing else, while a scanning LIDAR could also measure angles, providing with a 3D positioning. Parameter values for a given contact can be represented as a vector P_c.

In that case, for every contact c detected, for every parameter P_{ci} there is a measurement error E_{ci} such that

$$E_{ci}=F(P_{ci}). \tag{2}$$

Therefore for each contact we have two vectors P_c and E_c, the latter containing some form of measurement error representation, depending on what is required by the merging algorithm. Some algorithms today focus on parameters P_c and disregard E_c as a whole, or consider errors fixed across all detection ranges and angles.

But Elmenreich, W. and Leidenfrost, R. propose to use measurement variance from several previous observations of the same contact as a second parameter (Elmenreich and Leidenfrost, 2008). This has the advantage of providing localized variance, since measurements are taken in the general area where the object still is, unless it is moving exceptionally fast or measurement frequency is low.

They note, however, that measurement error correlation between sensors may affect the outcome, and the algorithm proposed by them to fuse sensor data will work across different sensors, but only so long as they have the same set of measured parameters P.

A robust, if demanding approach would be to have a sensor profile for each sensor used, built around a theoretical model or real life experimental data, that would contain a set of functions

$$E_i=F(P) \tag{3}$$

as a predictive model of measurement errors for each parameter E_i given observed set of parameters P (and not just P_i).

3.2. Heterogeneous sensors

It is far more advantageous to use different sensors providing a multitude of measured parameters. This may theoretically provide a wide range of contact parameters with precision as high as the best sensor providing this parameter, or, in case when more than one sensor is employed, potentially even more precise results.

A challenge arises on how to merge contacts from sensors with different measured contact parameters. Ulrich Kirchmaier *et al*. (2011) explore various approaches, such as using Kalman filter and Particle Swarm Optimization to solve this problem in a scenario with audio and visual sensors. They have demonstrated that, given specific sensor placement, it is possible to successfully fuse spatial sensor data.

Their experiment, however, requires triangulation, which means wide enough placement of at least two sensors measuring the same parameters. Given the distances at which UAVs may have to detect obstacles as well as their small sizes, that may not be possible or practical in our scenario. Furthermore, it limits merging algorithms to spatial parameters only.

Instead, if a multitude of sensors available measure n parameters across them, with some overlap, we have an n-dimensional space in which our contacts are presented, with measured parameters being constants and parameters not available on a specific sensor being variables. The task at hand is to clustered these contacts so that each cluster represents a feature, then construct feature parameters based on contact parameters in the cluster.

3.3. Merging the contacts

Clusterizing a set of observations is a simple and well established problem. However, in this particular case there are certain limitations and challenges. We have measurements with uncertainty and we don't have values for all axes for each measurement. Finally, we do not know the amount of clusters before hand.

Mahesh Kumar (2007) provides solutions to two of the three problems mentioned above in their hError Clustering Algorithm: making full use of measurement error and establishing the amount of clusters. By treating each observation as a Gaussian function with known parameters and mean corresponding to the measurement result, they were able to produce an algorithm that can prioritize higher quality measurements and stop at the right amount of clusters.

Another advantage to this algorithm is the complexity of $O(n^2)$, where n is the amount of contacts detected. Given that there are likely to be only a few sensors on a craft, and a reasonably small amount of obstacles within the range of a couple hundred meters from the observing craft, this should not be too complex to compute on modern embedded hardware.

The remaining problem to solve is dealing with missing measurements. We can treat missing parameters as either absence of similarity or absence of dissimilarity. The former will result in two observations of the same object across two sensors with no parameter overlap being classified as two different features (producing a false positive), the latter will classify two observations of different objects as a single feature (false negative). Having false positives is preferable to false negatives as far as safety is concerned.

Finally, since parameters measured have different units and scale, the question of scaling the axes in multidimensional space remains open. Natively hError algorithm uses Mahalanobis distance, but an explicitly weighted approach may yield better results in a situation where at least some of parameters are spatial and on the same scale.

The outline of the algorithm can be seen in Figure 2.

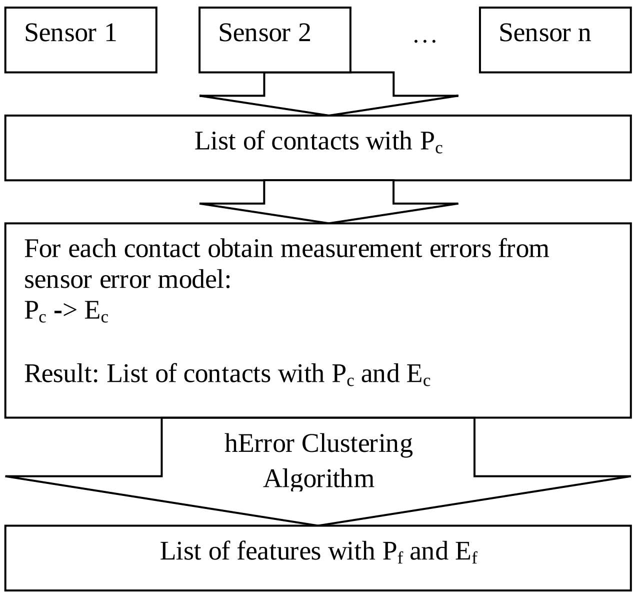


Figure 2. Data level fusion algorithm

Figure 3 shows an alternative algorithm where feature fusion is performed at the same time as contact fusion by incorporating features observed earlier with a penalty to their measurement precision, eventually retiring older features no longer observed. In either case, features retain an aggregated set of parameters P_f and corresponding measurement errors E_f as a result of clusterization.

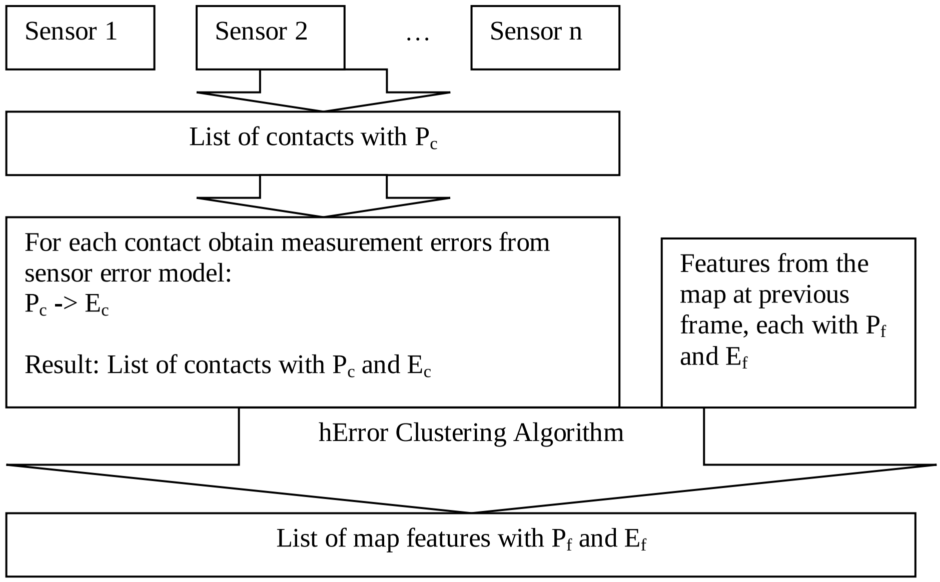


Figure 3. Alternative algorithm for fusing both data and feature levels

4. Conclusion

An algorithm was proposed to solve the problem of heterogeneous sensor fusion for the purposes of a decision support system to aide autonomous UAV navigation in uncontrolled airspace filled with potential obstacles.

Two versions of the algorithm can cover either the Data layer or Data and Feature layers, depending on the architecture of the system.

This particular algorithm is not tied to the specifics of each sensor, rather relying on sensor measurement error model for finer detail. Such approach makes the algorithm future-proof, easily incorporating newer sensors as they become available.

It is worth noting that while contact fusion implies working at sensor level, there is no restriction of what is considered a single sensor. Meaning, that the system tested by Kirchmeier *et al.* (2011) can be treated as a single sensor with better capabilities than the mere sum of its parts due to a more specific model used. Many commercially available sensor packages can also be treated as a single sensor, such as Microsoft Kinect, which has been widely used in research as an affordable imaging-rangefinding platform.

Given that at least some parameters used in clusterization are spatial, while others are not, it may be possible that a weighted function would yield better clusterization results than using Mahalanobis distance. Establishing principles on how to obtain such weights is the next logical step.

Finally, while theoretically this algorithm is not computationally intensive, with the worst part being $O(n^2)$, given potentially limited processing power in UAV onboard systems and unpredictable saturation of uncontrolled airspace, practical performance limits should still be examined.

References

1. Bhure, P. and Kalyanasundaram, P. (2016) Need for sensor fusion. TechTalk@KPIT, 9(1), 4–9.
2. Elmenreich, W. and Leidenfrost, R. (2008) Fusion of heterogeneous sensors data. In: *2008 International Workshop on Intelligent Solutions in Embedded Systems*, Regensburg, Germany, July 10-11, 2008. IEEE Xplore, DOI: 10.1109/WISES.2008.4623307
3. Kirchmaier U., Hawe S., Diepold K. (2011) Dynamical information fusion of heterogeneous sensors for 3D tracking using particle swarm optimization. In: *Information Fusion*, Volume 12, Issue 4, pp. 275-283, Elsevier.
4. Kumar, M., Patel, N.R. (2007) Clustering data with measurement errors. In: *Computational Statistics & Data Analysis*, Volume 51, Issue 12, pp. 6084-6101, Elsevier.
5. Lancovs, D. (2017) Introducing Fixed-Wing Aircraft into Cooperative UAV Collision Avoidance System. In: *Reliability and Statistics in Transportation and Communication. RelStat 2017. Lecture Notes in Networks and Systems*, vol 36. Springer, Cham, DOI 10.1007/978-3-319-74454-4_38
6. Pohl, C. and Van Genderen, J. L. (1998) Review article Multisensor image fusion in remote sensing: Concepts, methods and applications, In: *International Journal of Remote Sensing*, 19:5, 823-854, DOI: 10.1080/014311698215748

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 52-60
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

EVALUATION OF THE IMPACT OF THE NUMBER OF PICKING LOCATIONS ON THE TOTAL COST OF WAREHOUSE

***Raitis Apsalons* [1], *Gennady Gromov* [2]**

[1,2] *Transport and Telecommunication Institute, Riga, Latvia*
[1] *raitis.apsalons@inbox.lv*
[2] *gromov.g@tsi.lv*

Nowadays most of logistical centres are still using simplified picking technologies. Especially, if velocity of order lines is comparably low. Usually the total handling cost is optimising criterion for evaluation of the variants of organizing orders' picking process. In this paper pick and walk picking technology from pallet racks is revised. The picking area for each stock keeping unit (SKU) demands at least one picking location which here is defined as two bins: the first one on ground level and the second one – lies on level 1. For picking incoming customer orders, the orders' dividing principle is used to determine which quantities are going to be collected from storing area and which are going to be picked from picking area. The total handling cost has to be minimised comparing two opposite approaches of the layout of SKU: single picking location for each item or various picking locations for each item. Authors have developed mathematical formulas for calculation of total handling cost of both above mentioned approaches. The case study example of foodstuffs shows results of calculation of total handling cost in practice. Also the best appears approach of various picking locations; however, a choice of appropriate approach of the layout of SKU in PA is unequivocally.

Keywords: picking process, replenishment of items, orders' dividing principle, approaches of the layout of SKU, total handling cost

1. Introduction

Use of the smart systems becomes very popular in logistics. It is also very important to develop smart picking system for warehouses of the logistics centres (Benefits of an order picking system). In Latvia most of logistical centres are using simple picking technologies: the paper picking, RFID picking or more developed picking technologies such as: visual picking, picking by voice (Tompkins *et al.*, 2010; Harper, http://www.mwpvl.com; Lenoble *et al.*, 2018). Generally, it depends on velocity of order lines picked per paid man hour. In this paper is discussed picking area (PA) which is located into storing area (SA). The one row rack storing system available in the definite warehouse. Picking process will be realized by picking handling units (HU) and customer units (CU). The ground level and first level of pallet racks are used as PA. The one picking location of each stock keeping unit (SKU) consists of 2 pallets: 1 pallet on ground level and second one on the first level of rack. The replenishment is appropriated for moving the SKU's from SA to PA to avoid out of stocks in picking time interval. If picking location reaches critical stock level for single stock keeping unit, replenishment starts by the signal in warehouse management system (WMS). This approach is called as the Red Card principle (RCP) (Apsalons, 2012).

The total handling cost is optimising criterion for evaluation of the variants of organizing orders' picking process (Apsalons and Gromov, 2017a). The two approaches of the layout of SKUs in PA is analysed in this article: single picking location for each single SKU – the replenishment is realised in picking process and various picking locations for each single SKU or the replenishment is realised only just before picking process or after it. The main purpose of paper is to evaluate impact of the layout of PA on the total handling cost of the warehouse referring to the approaches of the layout of stock keeping units in PA. The definition of the scientific problem is that there are no direct mathematic formulas of evaluation of picking cost for comparing these two opposite approaches of the layout of SKU's in PA. The object of the research is storing and picking areas. The subject of the research concerns the total handling cost interconnection of replenishment process with the picking process.

2. The Approaches of the Layout of Items in PA

At first for each item (SKU) at least one picking address is planned in PA (Rushton and Walker,2007). The replenishment process can be realized by use of approaches of the layout of items in PA: either by the single picking location for each single item, when replenishment is realized in picking process or by various picking locations for each single item, when replenishment is realized only just before picking process or after it. Here main emphasis is on picking process without any interruptions, so that stock – out situations for any SKU would not occur (Apsalons and Gromov, 2017b).

The orders dividing principle (ODP) states that quantities for definite SKU of each order are divided into 2 parts (Apsalons and Gromov, 2015):

- For picking full pallets (FPLL) from SA – for single order usually expressed in customer units from SA.
- For picking HU and CU from PA – for single order usually expressed in customer units from PA.

We can further explore the total handling cost by comparing two approaches of the layout of SKU in PA:

- Single picking location for each single item – the replenishment is realised in picking process (see Fig. 1).
- Various picking locations for each single item – the replenishment is realised only just before picking process or after it.

In case of various picking locations for each single item, one single or various locations are allocated for each SKU (Apsalons, 2012). Fast moving SKU often require multiple pick face locations to ensure that sufficient picking stock is available to meet forecasted demand, while slower moving SKU may have only the one pick face location or, in some cases, may only be picked from their reserve location (Lukinskiy V. and Lukinskiy Vl, 2016).

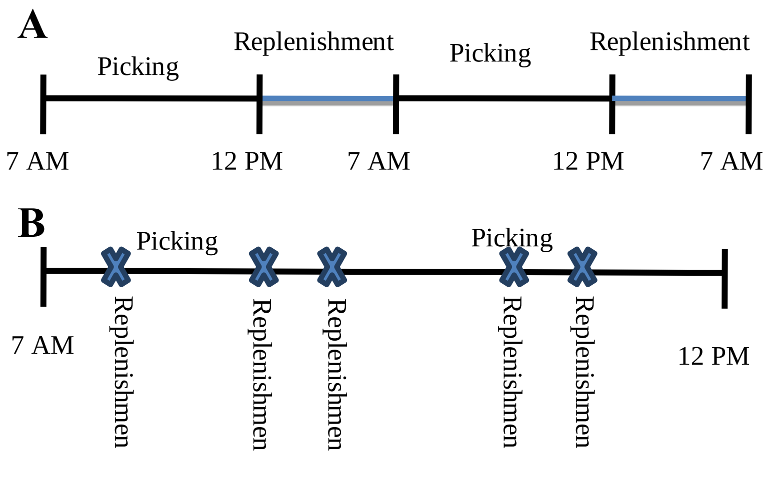


Figure 1. Approaches of the layout of items in PA: A) various picking locations for each single SKU (approach 2); B) one single picking location for each single SKU (approach 1)

The first approach defines that the replenishment of definite address is provided once the stock of definite items is below the critical level (Apsalons, 2012), and concrete inventory stock control method for procurement of goods is used in order to calculate this critical level. For this purpose re-order point (ROP) has been planned, and it depends on safety stock calculation, considering elimination of the stock-out (Apsalons and Gromov, 2017b; Lukinskiy V. and

Lukinskiy Vl, 2016). For example, the Min/Max stock controlling method can be adjusted for this purpose. It means that replenishment has been realized in uninterrupted picking process. Average replenishment cost could be more expensive than for the next approach.

The second approach eliminates replenishment in picking time. If it is not allowed, then quantities (stock) of each item in uninterrupted picking process have to be sufficient from the beginning of picking process till the end of it. Automatically it demands various picking addresses for each item, especially, if quantities to be picked exceeds two full pallets. Therefore the replenishment is realized outside of picking process: replenishment of picking addresses has to be before picking process has started (ERIM).

Additionally, besides approaches of the layout of items in PA, the routing strategies and methods have been awarded in picking process in PA. The main emphasis why routing strategies and methods are popular in the practice is diminishing total picking distance either for one single order or batch of orders (Dukic and Oluic, https://www.fing.edu.uy; Won and Olafson, 2005). Additionally, we can be aware of conditions referring to work by different SKU's. It means the allocation sequence of these SKU, assuming that they are going to pick from PA as HU and CU. These conditions can be expressed by parameters for forming right allocation sequence: as statistical value or measurement metrics.

3. Proposed Mathematical Formulas for Description of Total Handling Cost

The variant of organizing orders' picking process in the warehouse, proposed by authors, is picking from two separate zones, but PA is allocated in SA, additionally using ODP, from SA FPLL are collected (second and higher levels of pallet racks are used), but from PA - HU and CU (the first two levels of pallet racks are used). The M2G - man to goods picking system is revised in this paper.

The total handling cost of orders' picking process for two separate areas: SA and PA, generally should be evaluated:

$$THC_{SA\_PA} = \sum_{i=1}^{N} TPC_{SA\_FPLL\_i} + \sum_{i=1}^{N} TPC_{PA\_HU\_CU\_i} + \sum_{h=1}^{H} TRC_{(SA\_to\_PA)}, \quad (1)$$

where:

- THC_{SA_PA} – total handling cost for picking customer orders from SA and PA.
- i – each order line for all SKU's.
- N – the total number of picked customer order lines.
- $\sum_{i=1}^{N} TPC_{SA\_FPLL\_i}$ – the total picking cost of customer orders for extracting full pallets from SA.
- $\sum_{i=1}^{N} TPC_{PA\_HU\_CU\_i}$– the total picking cost of customer orders for collecting HU and CU from PA.
- $\sum_{h=1}^{H} TRC_{SA\_to\_PA}$ – the total replenishment cost from SA to PA.
- h – each replenishment from SA to PA (it is equal to 1 full pallet).
- H – number of replenishments.

If total picking costs from one general storing area is more than picking from separate areas SA and PA, considering additionally replenishment process and the PDO has been appropriated.

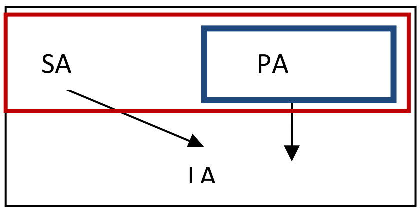


Figure 2. PA located into storing area (SA): the full pallets are picked from SA, but HU and CU from PA, after that cargo are consolidated and checked in loading area (LA)

Figure 2 characterizes ODP, but after order lines have been picked, the cargo of full and partial pallets are consolidated and checked in LA. This schema is in force for both above mentioned approaches; either single picking location is planned for each SKU or various picking locations for each SKU. The problem will arise for the first approach in case if quantity of single SKU at picking location to be picked in replenishment time interval will exceed stock quantity of this SKU at the same picking location, then picker cannot pick up demanded quantity, and stock – out will occur.

For example, if SKU_7 is an item with stock quantity 960 CU at picking location. Replenishment time interval is 20 minutes for transporting FPLL from SA to PA. Imagine that demanded picking quantity in excess is 1120 CU in the same replenishment time interval. Such kind of unpredicted excesses provide interruptions in customers' picking process, so stock - out is 960 – 1120 = - 160CU. Even the RCP has planned correctly by using Min/Max formulas, sometimes picking quantity in replenishment time interval could exceed the stock quantity at picking location. For resolving of such kind of situation, authors proposed to develop a plan of various picking locations for that single SKU by using calculation of the number of picking location. This is important because it is necessary to eliminate stock – out situation during picking process.

The total handling cost of orders' picking process for two separate areas: SA and PA (formula 1), excluding stock – out situations, can be expressed through use of average cost:

$$THC_{SA_{PA}} = \sum_{i=1}^{N} Q_{FPLLi} \times \gamma_i \times APC_{FPLL} + \sum_{i=1}^{N} Q_i \times (1-\gamma_i) \times APC_{PA} +$$
$$+ \sum_{i=1}^{N} Q_{FPLLi} \times (1-\gamma_i) \times ARC_{SA\_PA}, \quad (2)$$

where:

- γ_i – the coefficient of the part of the quantity picked in full pallets.
- Q_{FPLLi} – the total picking quantity expressed in full pallets (virtual pallets) for each SKU (FPLL):

$$Q_{FPLL\_i} = \frac{Q_{i*}}{A_{FPLLi}}, \quad (3)$$

where:

- A_{FPLLi} – the quantity of full pallet of each SKU (CU/FPLL), Q_i - the total picking quantity expressed in CU for each SKU (CU).
- $Q_{FPLLi} \times \gamma_i$ – the quantity in full pallets picked in SA for each SKU (FPLL/SA).
- APC_{FPLL} – average picking cost of full pallet from SA (EUR/FPLL).
- $(1-\gamma_i)$ – the coefficient of the part of the quantity picked in HU and CU.
- APC_{PA} – average picking cost of CU from PA (EUR/CU);
- ARC_{SA_PA} – average replenishment cost for transporting full pallets from SA to PA (EUR/FPLL).

The difference between these two approaches is when we are comparing average picking and average replenishment cost. So, we need to explore the formula 2 for each approach. It is assumed that APC_{PA1} and APC_{PA2} are average picking cost of CU from PA for approach 1 and approach 2 considerably, but for replenishment – ARC_{SA_PA1} and ARC_{SA_PA2} are average replenishment cost for transporting full pallets from SA to PA for approach 1 and approach 2. Other important restrictions for both above mentioned approaches are showed in Table 1.

Additionally, we need to plan stock – out situations for approach 1 during replenishment process. Then TSOC is total stock – out cost during replenishment process, and it can be calculated:

$$TSOC = \sum_{s=1}^{M} N_s \times ASOC_s, \quad (4)$$

where:
- N_s – number of picks with stock-out for each SKU.
- ASOC – average stock – out cost (EUR/pick).
- M – total number of stock-outs.

Table 1. Characteristics of the approaches of the layout of SKU in PA

Characteristics	Approach 1 – each SKU has single location	Approach 2 – each SKU has single location or various locations
1. Replenishment process provision	The RCP is obligatory a part of supporting the customers orders' picking	Replenishment is provided in separate time intervals, not during picking process
2. Calculation of the number of picking locations	No need to calculate the number of picking locations for each SKU	The calculation of the number of picking locations for each SKU is an essential part
3. Setting up the MIN/MAX levels in WMS	It is very important to set up MIN – critical level of each SKU when stock reaches this level, replenishment starts immediately.	No need to set up or to calculate MIN – critical level of each SKU, because right quantities are provided during picking process at PA
4. Total travelling distance during picking process	Travelling distance is minimised, because each SKU has 1 picking address in PA	Travelling distance is prolonged, because each SKU has 1 or various addresses in PA
5. Probability of stock - out	Stock – out situations can occur in picking process, during replenishment process will realise	No stock – out situations can occur in picking process

The total handling cost of orders' picking process for two separate areas: SA and PA (formula 2) averring conditions in formulas (3) and (4) ***for approach 1*** can be calculated:

$$THC_{SA_{PA1}} = \sum_{i=1}^{N} Q_{FPLLi} \times \gamma_i \times APC_{FPLL} + \sum_{i=1}^{N} Q_i \times (1-\gamma_i) \times APC_{PA1} + \\ + \sum_{i=1}^{N} Q_{FPLLi} \times (1-\gamma_i) \times ARC_{SA\_PA1} + \sum_{s=1}^{M} N_s \times ASOC_s. \quad (5)$$

The total handling cost of orders' picking process for two separate areas: SA and PA (formula 2) averring conditions in formulas (3), (4) ***for approach 2*** can be calculated:

$$THC_{SA_{PA2}} = \sum_{i=1}^{N} Q_{FPLLi} \times \gamma_i \times APC_{FPLL} + \sum_{i=1}^{N} Q_i \times (1-\gamma_i) \times APC_{PA2} + \\ + \sum_{i=1}^{N} Q_{FPLLi} \times (1-\gamma_i) \times ARC_{SA\_PA2}\ , \quad (6)$$

APC_{FPLL} – average picking cost of full pallet from PA is assumed the same for both approaches. However, $APC_{PA1} < APC_{PA2}$ – average picking cost at PA for approach 1 is less than for approach 2, and $ARC_{SA\_PA1} < ARC_{SA\_PA2}$ due to one or various picking locations for single SKU.

4. Experiment: Case Study Analysis of the Approaches of the Layout of SKU in PA for Calculation THC

An optimisation criterion for the layouts' approaches is the total handling cost (THC), and it tends to be minimised. As research instrument has chosen a case study. The case study is an in depth study of a particular situation rather than a sweeping statistical survey (Case Study

Research Design). Also, method of study is especially useful for trying to test theoretical models by using them in real world situations. This case study deals with two opposite choices of the right decision for minimising THC. The research has done in a well – known foodstuffs logistics centre in Latvia by authors. In this logistics centre PA included in SA, and picking is realised as "pick and walk" system. The ground level and first level of pallet racks are used as PA. The one picking location of each stock keeping unit (SKU) consists of 2 pallets: 1 pallet on ground level and second one on the first level of rack. The replenishment is appropriated for moving the SKU's from SA to PA. In our research example case 10 popular foodstuffs SKU are taken into account. The 100 customer orders are realized for picking 10 SKUs' from SA and PA. Picking process duration is 2 hours and main parameters are shown in Table 2.

Table 2. Data base of foodstuffs SKU based on customers' orders information in a day

Parameters	SKU1	SKU2	SKU3	SKU4	SKU5	SKU6	SKU7	SKU8	SKU9	SKU10
$MINV_i$	6	1	5	5	4	1	22	11	12	1
$MAXV_i$	119	74	234	121	84	51	1219	518	613	84
Q_{ai}	58.43	37.03	124.97	70.59	47.53	25.48	608.09	272.57	322.53	41.19
Q_i	5843	3666	12247	6847	4705	2497	60201	26984	31930	4119
A_{FPLLi}	100	140	160	80	120	160	180	200	440	66
Q_{FPLLi}	58.43	26.19	76.54	85.59	39.21	15.61	334.45	134.92	72.57	62.41
Q_{FPLLi_SA}	19	0	32	43	0	0	286	94	28	26
γ_i	0.33	0.00	0.42	0.50	0.00	0.00	0.86	0.70	0.39	0.42
N_o	100	99	98	97	99	98	99	99	99	100
Q_{cui}	3943	3666	7127	3407	4705	2497	8721	8184	19610	2403
N_{soi}	30	0	40	38	20	0	54	30	40	23

Data base of foodstuffs in Table 2 is calculated from customers' orders information, and therefore have unequal total picking quantities (irregularity) for each order:

- $MINV_i$ – minimum value or picking quantity per order for each SKU (CU/order).
- $MAXV_i$ – maximum value or picking quantity per order for each SKU (CU/order).
- Q_{ai} – average picking quantity per order for each SKU (CU/order).
- Q_i – total picking quantity per order for each SKU (CU/order).
- A_{FPLLi} – pallets' quantity for each SKU (CU/FPLL).
- Q_{FPLLi} – the total picking quantity expressed in full pallets (virtual pallets) for each SKU (FPLL/100 orders).
- Q_{FPLLi_SA} – the picking quantity expressed in full pallets picked from SA for each SKU (FPLL/SA).
- γ_i – the coefficient of the part of the quantity picked in full pallets from SA.
- N_o – number of orders for each SKU (orders).
- Q_{Cui} – the picking quantity from PA for each SKU (CU/PA).
- N_{SOi} – calculated number of stock - outs, assuming that 2 picks can be realised during replenishment.

In Table 3 total handling costs have been calculated by authors, using formula (5) for approach 1 and formula (6) for approach 2.

Table 3. Calculation of total handling costs for approaches 1 and 2

Parameters	SKU1	SKU2	SKU3	SKU4	SKU5	SKU6	SKU7	SKU8	SKU9	SKU10
APC_{FPLL}	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54	3.54
APC_{PA1}	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
APC_{PA2}	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
ARC_{SA_PA1}	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222
ARC_{SA_PA2}	1.344	1.344	1.344	1.344	1.344	1.344	1.344	1.344	1.344	1.344
ASOC	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222	1.222
TPC_{SA_FPLLi}	67.18	0.00	113.14	152.03	0.00	0.00	1011.19	332.35	99.00	91.93
$TPC_{PA1\_HU\_CUi}$	13.44	12.49	24.29	11.61	16.03	8.51	29.72	27.89	66.83	8.19
$TPC_{PA2\_HU\_CUi}$	26.87	24.99	48.57	23.22	32.07	17.02	59.44	55.78	133.65	16.38
TRC_{SA_PA1i}	48.17	31.99	54.41	52.02	47.90	19.06	59.19	49.99	54.44	44.48
TRC_{SA_PA2i}	52.98	35.19	59.86	57.23	52.69	20.97	65.10	54.99	59.89	48.92
$TSOC_{1i}$	36.65	0.00	48.86	46.42	24.43	0.00	65.97	36.65	48.86	28.10
THC_{1i}	165.43	44.48	240.70	262.09	88.36	27.57	1166.06	446.87	269.13	172.69
THC_{2i}	147.03	60.17	221.57	232.48	84.75	37.99	1135.73	443.11	292.54	157.23

It is possible to obtain average picking cost, average replenishment cost and average stock – out cost by using on activities based cost calculation in the warehouse in Table 3, but total picking and handling costs - by use of developed formulas (5) and (6):

- APC_{FPLL} – average picking cost of full pallets for each SKU in SA (EUR/FPLL).
- APC_{PA1} – average picking cost of customer units for each SKU in PA1 (EUR/CU).
- APC_{PA2} – average picking cost of customer units for each SKU in PA2 (EUR/CU).
- ARC_{SA_PA1} – average replenishment cost of full pallet from SA to PA1 (EUR/FPLL).
- ARC_{SA_PA2} – average replenishment cost of full pallet from SA to PA2 (EUR/FPLL).
- ASOC – average stock – out cost (additional movement of full pallet) (EUR/FPLL).
- TPC_{SA_FPLLi} – calculated total picking cost of full pallets from SA for each SKU (EUR/SA).
- $TPC_{PA1\_HU\_CUi}$ – calculated total picking cost of HU and CU from PA1 for each SKU (EUR/PA).
- $TPC_{PA2\_HU\_CUi}$ – calculated total picking cost of HU and CU from PA2 for each SKU (EUR/PA).
- TRC_{SA_PA1i} – calculated total replenishment cost of full pallet from SA to PA1 for each SKU (EUR).
- TRC_{SA_PA2i} – calculated total replenishment cost of full pallet from SA to PA2 for each SKU (EUR).
- $TSOC_{1i}$ – calculated total stock – out cost for approach 1 for each SKU (EUR/PA1).
- THC_{1i} – total handling cost for each SKU for approach 1 (EUR).
- THC_{2i} – total handling cost for each SKU for approach 2 (EUR).

5. Conclusions

In case study example calculation of THC is based on analysis of information of customer orders in a day. Therefore, the structure of customer orders expressed as picking of FPLL from SA and HU and CU from PA plays essential role, and may vary every day. The THC_1 for approach 1 in total is 2883 EUR of picking 100 customer orders, but THC_2 for approach 2 is 2813 EUR for the same number of orders. From here the best appears approach 2.

As replenishment duration in case study is assumed two following picks and very often picking quantity of two following picks exceeds pallets' quantity, the stock – out situations will occur. It could happen just only for approach 1 with single picking location for each SKU. Therefore, additional total stock – out cost for approach one is calculated as 336 EUR. Without evaluation of stock out cost approach 1 seems very attractive: the THC_1 could be 2547 EUR, but this is not correct calculation.

Additionally, from the one side the approach 2 is winner referring to THC calculation, but from another side the approach 2 demands calculation of the number of picking locations for each SKU. It can be realized using the model of the number of picking locations developed by authors in earliest researches. However, it means that PA will be bigger for approach 2, and travelling distance consequently will be more because prolonged PA. Even approach 2 has appropriated routing methods of PA, the picking time for movement will be longer. The adequate solution for this problem is to developed approach 3: combined approach from previous two approaches. If replenishment duration is two following picks and picking quantity of two following picks does not exceed pallets' quantity, then single location is planned for such kind of SKU. Otherwise the number of picking locations can be calculated for approach 2.

Developed formulas of evaluation of total handling cost in our case study have approbation in a well – known foodstuffs logistics centre in Latvia. Thus, this research has a practical application.

Acknowledgements

This work has been supported by the ALLIANCE project (http://alliance-project.eu/) and has been funded within the European Commission's H2020 Programme under con-tract number 692426. This paper expresses the opinions of the authors and not necessarily those of the European Commission. The European Commission is not liable for any use that may be made of the information contained in this paper.

References

1. Apsalons, R., Gromov, G. (2017a) Methodology of evaluation of the impact of picking area location on the total costs of warehouse. In: *Reability and Statistics in Transportation and Communication*.
2. Apsalons, R., Gromov, G. (2015) Using of logistics' principles for picking items in railway warehouses. In: *Development of infrastructure and logistics technologies of transport systems (in Russian). International scientific – practical conference*, pp. 93–100. Sankt – Petersburg.
3. Apsalons, R., Gromov, G. (2017b) Using the Min/Max method for replenishment of picking locations. In: *Transport and Telecommunication Journal* - https://www.degruyter.com/view/j/ttj.2017.18.issue-1/ttj-2017-0008/ttj-2017-0008.xml
4. Apsalons, R. (2012) *The management of logistics centres* (in Latvian). Burtene, Latvia.
5. *Benefits of an order picking system*. www.kardex–remstar.com
6. *Case Study Research Design*. https://explorable.com/case-study-research-design
7. *Dematic Global Website. Replenishment*. - http://www.dematic.com/en/supply-chain-solutions/by-supply-chain-function/replenishment
8. Dukic, G., Oluic, C. *Order picking methods: improving order picking efficiency*. https://www.fing.edu.uy/inco/eventos/icil05/03-wed/F1-Dukic.pdf
9. ERIM. *Routing strategies*. https://www.erim.eur.nl/centres/material-handling-forum/research-education/tools/calc-order-picking-time/what-to-do/routing-strategies/

10. Harper, J. *Distribution centre order picking technologies compared*. - http://www.mwpvl.com/html/order_pick_technologies.html
11. Lenoble N., Frein Y., Hammami R. (2018) Optimization of Order Batching in a Picking System with a Vertical Lift Module. In: *Temponi C., Vandaele N. (eds) Information Systems, Logistics, and Supply Chain. ILS 2016. Lecture Notes in Business Information Processing*, vol 262. Springer, Cham, France.
12. Lukinskiy, V., Lukinskiy,Vl. (2016) Evaluation of the influence of logistic operations reliability on the total costs of supply chain. In: *Transport and Telecommunication. Volume 17*, No. 4, pp. 307 – 313.
13. Rushton, A., Walker, S. (2007) International Logistics and Supply Chain Outsourcing. From local to global. In: *Alan Rushton and Steve Walker*.
14. Tompkins, J.A., White, J.A., Bozer, Y.A., Tanchoco, J.M.A. (2010) *Facilities planning*. 4th edition, John Wiley&Sons, Ltd. UK.
15. Won, J., Olafson, S. (2005) Joint order batching and order picking in warehouse operations. In: *International Journal of Production Research*. 4/1/2005, pp. 1427 - 1442.

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 61-62
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

JOINTLY PLANNING URBAN LOGISTICS – BRIDGING THE GAB BETWEEN URBAN PLANNING AND LOGISTICS PLANNING

Tom Assmann [1,3], Fabian Behrendt [2,3]

[1] Institute of Logistics and Material Handling Systems, Otto von Guericke University Magdeburg,
tom.assmann@ovgu.de
[2] SRH Mobile University, Riedlingen
[3] Fraunhofer Institute for Factory Operations and Automation IFF, Magdeburg, Germany

Keywords: urban logistics, location planning, cargo bike, urban freight, transshipment facility

Global warming, urbanization and severe air pollution are prompting most European municipalities to reorganize their transportation systems. Along with restricting car use and building up modes of active transportation, “greening” urban logistics is increasingly becoming a priority. Logistics service providers’ (LSP) networks are generally adapted for car-centric infrastructures and thus greatly affected by traffic congestion. This is becoming a major issue confronting booming e-commerce business and their deliveries.

What is even more important is the provision of land. Logistic activities had been removed from inner city areas for the last decades and are predominantly based at the city’s outskirts. From there uncountable volumes of trucks and delivery vans are entering the city daily, adding up to congestion and emissions. New modes of transport like cargo bikes and light electric vehicles demonstrate to adapt better to dense, liveable and green urban fabrics. However, the need new facilities and infrastructure for operating efficiently and should be adapted the specific fabric of the area of operation. While municipalities have to manage and provide land for essential infrastructure, they have virtually no guidelines for identifying suitable sites for new facilities based on location and throughput. This prompts the necessity for logistics and urban planners to jointly develop long term logistics systems which allow to determine the right sites and infrastructure needed.

Following, we will briefly introduce the joint planning scheme for urban logistics. It follows the principle of spatial emergence (Frick, 2011) describing hierarchical planning scales of urban planning which is merged with the logistics micro-, meso-, and macro planning levels introduced by (Krampe and Lucke, 2012; Fleischmann *et al*., 2008).

The large-area planning scale allows structuring the region's and the city's land use, analysing the urban fabric and analysing interactions between different types of settlement entities, encompassing the flows between the city and (suburban) logistic facilities (Hesse, 2007). The latter is placed in supra-regional network-planning. It is the scale for strategically plan places for logistic operations and facilities. Combining regional and city scale is reasonable because a) both scales predominantly focus on land-use and infrastructure corridors and b) logistics do not much consider administrative boundaries.

The subarea scale is a specific district or quarter with a distinct urban fabric. It is the level for planning a sustainable city transformation and, therefore, the space for jointly planning urban logistic concepts fitting to the specific fabric of a quarter (e.g. on this level, it can be examined in detail whether a cargo bike scheme is viable or not). It is the level to analyse and plan functions and interactions, determine locations for facilities, plan accessibility, restrictions and infrastructure, choose means of transport and logistics services.

The micro scale is the level of a street and its building blocks alongside. It describes the place of the realisation of facilities and infrastructure. It is dominated by the interrelation between the integration into the direct urban surrounding (urban design, human dimension) and the composition of a certain logistics facility according to logistical needs. Hence, detailed planning and analysis of suitable configuration of infrastructure, buildings, functions and public spaces as well as their design take place here.

References

1. Fleischmann, B., Arnold, D., Papier, F., Thonemann, U., Scholl, A., Furmans, K., Kuhn, A., Wenzel, S., Domschke, W., and Drexl, A. (2008) "*Grundkonzepte, Grundlagen*," in Handbuch Logistik, D. Arnold, H. Isermann, A. Kuhn, H. Tempelmeier, and K. Furmans, Eds. Berlin Heidelberg: Springer Verlag, 2008, pp. 1–211.
2. Frick, D. (2011) *Theorie des Städtebaus*. Tübingen Berlin: Ernst Wasmuth Verlag.
3. Hesse, M. (2007) *Logistischer Wandel in der Region*, Z. Wirtschgeogr., vol. 51, pp. 93–107.
4. Krampe, H. and Lucke, H.-J. (2012) "*Einführung in die Logistik*," in Grundlagen der Logistik, 4. Auflage., H. Krampe, H.-J. Lucke, and M. Schenk, Eds. München: Huss-Verlag, 2012, pp. 17–36.

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 63-66
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

AN OUTLOOK FOR THE USE OF COBOTS IN LATVIA

Andris Spulis

RISEBA University,
Latvian logistics association
andris.spulis@spulisconsulting.com

This paper presents critical review of scientific-research literature in support of the management decisions of the company and company interest group (association, cluster) on the possible use of cobots for a productivity increase and sustainable competitiveness in the logistics sector in Latvia. Several sources indicate manufacturing, healthcare, law enforcement, construction and agriculture as most prospective areas of cobots' applications. Latvia is not a powerhouse of manufacturing. Implementations of cobots in Latvia could be facilitated by the essential elements of smart logistics, logistics management and supply chain management (SCM), often called "Logistics 4.0." An important factor for cobots future success could be the positive mood of the Latvian society on robots in general. Human and cobot interaction model can influence cobot's implementation results significantly.

Keywords: robots, cobots, human and robot team, human and cobot interaction model

1 Introduction

The author's interest lies in carrying out an in-depth analysis of the possibility of the application of cobots in Latvian companies initialized by a robot and labour costs comparison provided in source (Hollinger, 2016). In year 2014 an average one hour costs for a robot service (about €6/h) was below average labour force costs in China (about €8/h) and Eastern European countries (about € 11/h). Average cost of labour force in Germany (around € 40/h) was about 8 times as much as average robot service one-hour costs. The intention to carry out in-depth analysis was reinforced by the opinion „Advances in computing power and robotic technology along with a smaller price tag, an average of $24,000 each, make cobots a realistic option for small- and medium-sized businesses" (Marr, 2018).

Study spotlight for logistics sector in Latvia:

- Insufficient productivity, which can be increased by innovation in order to facilitate automation of performing low -value added tasks;
- Decrease of labour availability and rising labour costs;
- The possibility of facilitating automation processes in the services sector by reducing the overall cost of the sector by applying a chain value chain model;
- The availability of EU support instruments for innovative and productivity-oriented cross-sectoral cooperation activities for the 2014-2020 and for period beyond.

2 Cobot's Current Status and Development Trends

Latvia holds 49th place in the „The Global Competitiveness Index (GCI) 2016-2017 Rankings" among 138 countries (The Global Competitiveness Report, 2016-2017). GCI algorithm includes 12 parameters (Pillars).

Latvia's overall valuation is negatively affected by the relatively low (69-th place) rating for "12-th pillar: Innovation". GCI data show that 8 out of 10 countries with the highest overall rating GCI index are also among the TOP10 for the index "Innovation" rating (Switzerland

(1/1), US (3/2), Netherlands (4/6), Germany (5/3), Sweden (6/5), United Kingdom (7/9), Japan (8/4), Finland (10/7). The study is based on the assumption that Cobot could be the innovative and economically justified solution for several services sectors in Latvia. The cost of each individual cobot deployment costs may be reduced through clusters support mechanisms, including by-flooding a chain value chain model.

In most comprehensive meaning, the term cobot is defined in the following way (wikipedia.org/wiki/Cobot) „A cobot or co-robot (from collaborative robot) is a robot intended to physically interact with humans in a shared workspace. This is in contrast with other robots, designed to operate autonomously or with limited guidance, which is what most industrial robots were up until the decade of the 2010s. Cobots were invented in 1996 by J. Edward Colgate and Michael Peshkin, professors at Northwestern University. A 1997 US patent filing describes Cobots as "an apparatus and method for direct physical interaction between a person and a general purpose manipulator controlled by a computer." Cobots are produced by not less than 40 companies at nowadays. The field pioneer and leader (Universal Robots) uses its own definition (Østergaard, 2018). "Cobots are robots that: a) comprise small-footprint robotic arms only; b) are safe for people to work with and around – no need for protective fencing; c) are easy for ordinary operators to program, deploy and re-deploy; d) serve as tools for operators, not devices that replace human workers; e) enable companies to keep control of their own automated processes"

The cabots' current market status is described as follows (www.marketsandmarkets.com, 2017) „Collaborative Robots Market is expected to be worth USD 4.28 Billion by 2023, growing at a CAGR of 56.94% between 2017 and 2023. Europe held largest share of collaborative robots market in 2016. The growth of the market in Europe was driven by strong government support to promote factory automation solutions, thus supporting Industry 4.0 drive. Industry 4.0 is a set of the measures focused to the new opportunities that Fourth Industrial Revolution is creating for German industry". The term "Fourth Industrial Revolution" (www.marketsandmarkets.com, 2018) is commonly understood to mean a range of manufacturing technologies that fuse the physical and digital worlds, with breakthroughs in a) artificial intelligence (AI), b) robotics, c) the Internet of Things (IoT), d) autonomous vehicles and c) 3D printing seen as main drivers". The above mentioned optimistic forecast should be assessed with caution as another source indicates (www.cbinsights.com, 2018) „Robots can easily complete repetitive, predictable tasks. But for less structured tasks, such as picking out an item from a random assortment, there are far more unique scenarios where special handling must be calculated by an algorithm. To be truly collaborative, AGV (Autonomous Ground vehicles) must autonomously "see" human obstacles and act accordingly .When analysing the use of cobot, it should be taken into account that their practical use is also hampered by common robotics sector problems. *Vision technology* allowing robots to identify and navigate around objects (including people) has been slow to improve. *Dexterity issues*: Robot gripping and mechanical capabilities are still limited. *LowROI*: Low labor costs have prevented the need for widespread integration of robotics in fields like agriculture and manufacturing. Source (www.cbinsights.com, 2018) also analyses recent success and forecasts progress "Teaching robots to map and manipulate objects is a difficult task. But a number of research developments out of Google's DeepMind and UC Berkeley have demonstrated success with one-shot learning, where the cobots can recognize new objects without a vast trove of training data. Future robots may only need to watch a human once to learn a task, or could be programmed using VR gesture control (a method being pioneered by Covariant). Source (http://news.mit.edu/2017) informs the latest brain-controlled robots' related achievements. „MTA team from MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) and Boston University is working on a problem, creating a feedback system that lets people corrects robot mistakes instantly with nothing more than their brains. Robots and cobots have both advantages and advantages as mentioned in (Gross, www.rg-robotics.com, 2018).

Table 1. The Pros and Cons of Cobots vs. Industrial Robots according (Gross, www.rg-robotics.com, 2018)

	PROS	CONS
COBOTS	• They can coexist with human beings sharing the same work area. • Reduced primary cost of integration and changes to the workspace to accommodate the cobot when a restricted area is not required. • Easy programming and integration. • In less than a year, one can get back the money invested in the robot.	• The cobot may require a restricted working area to ensure employee's safety. The initial cost of setting up the cobot's cell can be substantial. • Work speed can be hampered if there are safety measures put in place. For instance, the cobot may have to stop every time it senses the presence of a human being in its working environment. • Because the robots are collaborative, they cannot work without human assistance and supervision.
INDUSTRIAL ROBOTS	• They require less human supervision, have a high-efficiency rate, much more than humans, even when expected to produce high volumes. • The machine can be fully automated which makes it ideal to handle tasks too risky or to involving for human beings. They can be more accurate and precise than people. • 12 to 18 months return on investment. • Can still be used in collaborative tasks but the level of risk should be accessed beforehand.	• Not appropriate when low volumes of production are required. • Because the robot may need a working cell, this may require changes to the workplace ground set up. • It is not easy to alter the processes. This may make the process more costly when external resources are needed to accomplish a task. • Employees need training or an external expert to initiate, run and maintain the robot's program may be needed. • The initial cost of acquiring a robot may be the same as that of a cobot, but when a work cell is needed, this may raise the price.

3 Conclusions

International Federation of Robotics to see beyond (IFR, April 2017) "The future will be robots and humans working together. Robots substitute labour activities but do not replace jobs. Less than 10% of jobs are fully automatable. Increasingly, robots are used to complement and augment labour activities; the net impact on jobs and the quality of work is positive. Automation provides the opportunity for humans to focus on higher skilled, higher-quality and higher-paid tasks ". The study (Collaborative Robots:.., www.eletimes.com, 2017) at the MIT undertaken by Julie Shah discovered that teams of human and robot collaborators worked with better efficiency and precision with higher productivity, when compared to an all human or an all robot team. This co-operative process reduced the human idle time by 85% and she also observed that humans do not mind robots taking the lead. Several sources indicate Manufacturing, Healthcare, Law Enforcement, Construction and Agriculture as most prospective areas of Cobots' applications.

Latvia is not a powerhouse of Manufacturing. Implementations of cobots in Latvia could be facilitated by fact that Industry 4.0 means more than just the smart factory or the implementation of technologies. Industry 4.0 contains the essential elements of smart logistics, logistics management and supply chain management (SCM), often called "Logistics 4.0." An important factor for cobots future success may be the positive mood of the Latvian society on robots in general. "Baltic International Bank (BIB) Latvia Barometer" data shows (Baltic International Bank Latvijas barometrs, 2018) that "most of those surveyed (52%) believe that robots will be able to replace people who perform a simple physical work. There are also a lot of them (49%) who are convinced that people who do difficult physical work could be replaced by robots. At the same time, Maris Purins, chief executive of Baltic International Bank's Information Technology Administration, warns (Puriņš, 2018) "assuming that conscious equipment (*ar apziņu apveltītas iekārtas)* in the future will be created; it will put humanity in front of many very important morally ethical problems".

Research questions for further investigation

The latest publications (Robert, 2018; Jung and Hinds, 2018) point to an ongoing problem that is the subject of future research. The advances in technology have far outpaced ours knowledge with regard the relationship between humans and robots. The research question will be what interaction models can be implemented for human and cobot interaction, what factors influence cobots's implementation results and what can be considered as drivers for influencing and motivating human team and individuals to operate together with robot team.

References

1. Hollinger, P. (2016) *Meet the cobots: humans and robots together on the factory floor*. Accessed October 4th 2018. - https://www.ft.com/content/6d5d609e-02e2-11e6-af1d-c47326021344
2. Marr, B. (2018) *The Future of Work: Are You Ready for Smart Cobots?* Accessed October 4th 2018. - https://www.forbes.com/sites/bernardmarr/2018/08/29/the-future-of-work-are-you-ready-for-smart-cobots/#48796bbb522b
3. The Global Competitiveness Report 2016-2017_FINAL.pdf
4. https://en.wikipedia.org/wiki/Cobot
5. Østergaard, E.H. (2018) *Whitepaper: The role of Cobots in Industry 4.0*. 14 p. Accessed October 3rd 2018 - https://info.universal-robots.com/the-role-of-cobots-in-industry4.0
6. *Collaborative Robots Market Analysis by Payload Capacity* (Up to 5kg, Up to 10kg, Above 10kg), By Application (Assembly, Pick & Place, Handling, Packaging, Quality Testing, Machine Tending, Gluing & Welding), By Industry, And Segment Forecasts, 2018 – 2025. Accessed October 4th 2018. - https://www.marketsandmarkets.com/PressReleases/collaborative-robot.asp
7. https://www.marketsandmarkets.com/PressReleases/collaborative-robot.asp. Accessed October 4th 2018
8. *Smaller Collaborative Robots are Disrupting the Robotics Industry*. July 18, 2018. Accessed October 4th 2018. - https://www.cbinsights.com/research/collaborative-robots-reinvent-industries/#labor
9. http://news.mit.edu/2017/brain-controlled-robots-0306. Accessed October 4th 2018
10. Gross, P. (2018) *The Pros and Cons of Cobots vs. Industrial Robots*. (Posted by Patrick Gross). Jun 16, 2018. Accessed October 3rd 2018. - https://www.rg-robotics.com/the-pros-and-cons-of-cobots-vs-industrial-robots/
11. The Impact of Robots on Productivity, Employment and Jobs. *A positioning paper by the International Federation of Robotics*. April 2017
12. *Collaborative Robots: An innovation for Industry 4.0*. Accessed October 4th 2018. - https://www.eletimes.com/collaborative-robots-innovation-industry-4-0
13. Baltic-International-Bank-Latvijas-barometrs-tehnologijas-02.2018.pdf
14. Puriņš M. (2018) *Roboti vai cilvēki? Latvijas sabiedrība ir piesardzīga*. - http://www.delfi.lv/bizness/versijas/maris-purins-roboti-vai-cilveki-latvijas-sabiedriba-ir-piesardziga.d?id=49823241
15. Robert L.P. (2018) Motivational theory of human robot teamwork. *Int Rob Auto J*. 2018;4(4):248–251. DOI: 10.15406/iratj.2018.04.00131
16. Jung, M. and Hinds, P. (2018) Robots in the Wild: A Time for More Robust Theories of Human-Robot Interaction. *ACM Trans. Hum.-Robot Interact*. 7, 1, Article 2 (May 2018), 5 pages. https://doi.org/10.1145/3208975. Accessed October 4rd 2018 - *https://riglab.infosci.cornell.edu/assets/papers/wild.pdf*

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No. 2, 67-73
Transport and Telecommunication Institute, Lomonosova 1, Riga, LV-1019, Latvia

SMART WAREHOUSE CONCEPT AND UNDERLYING TECHNOLOGIES: STATE-OF-THE-ART

Aleksandrs Avdeikins [1], Mihails Savrasovs [2]

[1,2] Transport and Telecommunication Institute
Riga, Latvia, Lomonosova street 1
[1] avdey@avdey.lv
[2] Savrasovs.M@tsi.lv

This paper discusses how the state-of-the-art solutions and technologies helps to build smart logistics warehouse within vision of industry 4.0. Paper focused on use of smart technologies for data collection and mistake prevention, automated work scheduling, demand driven planning, problem alerting and other fundamental operations in smart warehouse. In the paper authors linked technologies to warehouse operations and discussed concept of smart warehouse and it's key areas.

Keywords: smart warehouse, AI, Industry 4.0

1. Introduction

Based on the definitions of Smart Services and Smart Products, Uckelmann (2008) describes Smart Logistics as a field that involves the application of various technical means in order to get data on the material flows and to process this data for monitoring and other purposes.

With rapid development of technologies, world came to the fourth industrial revolution, Industry 4.0. As shown on Figure 1, there were developed variety technologies can be used in smart warehouse and possible research topics based on that technologies are:

- Human mistake prevention techniques;
- Human activity recognition;
- Multi-Robot collaboration;
- Efficient work scheduling;
- AI based DSS (decision support systems).

Figure 1. Industry 4.0 Technologies

To be competitive on the market every warehouse should consider change to the smart warehouse. It plays a major role in success of supply chain by enhancing the overall effectiveness and efficiency of the logistics system.

The paper objectives are:

- to determine concept of the smart warehouse;
- to determine the various technology used by smart warehouse;
- to discuss impact of technology on logistics and supply chain management.

In a traditional warehouse, the operations of inbound and outbound flows registered manually or with help of devices like PDA's in ERP (enterprise resource planning) or WMS (warehouse management system) system. Such operations are very expensive and gives a big probability of human mistake. Having a big amount of data integrity mistakes heads to the necessity of continuous stock counting. Development of technology and gave a chance to change traditional warehouse to smart and minimise the chance of mistakes. AI based systems and solutions help us to take decisions on the warehouse control and management faster and on time.

2. IT and Technology Importance in Logistics

Information Technology is a vital element for 3PL performance because the integration of logistics provider systems with its clients is essential. Moreover, Information Technology links members of a supply chain, such as transportation companies, distributors, manufacturers, and retailers as it automates some elements of the logistics workload such as order status inquires, consignment tracking, inventory management and order processing.

The main questions to answer:

- What technologies are most suitable to various 3PL processes and supply chain management?
- What are the main characteristics of the smart warehouse?

Table 1 provides overview and link warehouse operations to its technologies.

Table 1. Technology use matrix in warehouse operations

Operation name	IoT / RFID	AI	Drones	EDI Communications	PDA/Tablets	BarCodes / Optical recognition
Inbound	X	X		X	X	X
Sorting		X			X	X
Warehousing		X			X	X
Slotting		X			X	X
Inventory management/ Counting		X	X			
Outbound	X	X		X	X	X
Distribution	X	X		X	X	X

2.1. RFID

RFID is an automated identification technology. It was developed to identify and capture related information on the products that circulate throughout the supply chain without human intervention in the process (Ahson and Ilyas, 2008).

RFID is composed of three main components: the RFID tag, the RFID reader and the antenna (that allows communication between the tag and the reader). The data captured by the reader is sent to a component called RFID Middleware, which then transforms the captured data into meaningful information that is necessary for the business applications (ex. an ERP system) (Lieshou *et al*., 2007), as shown on Figure 2.

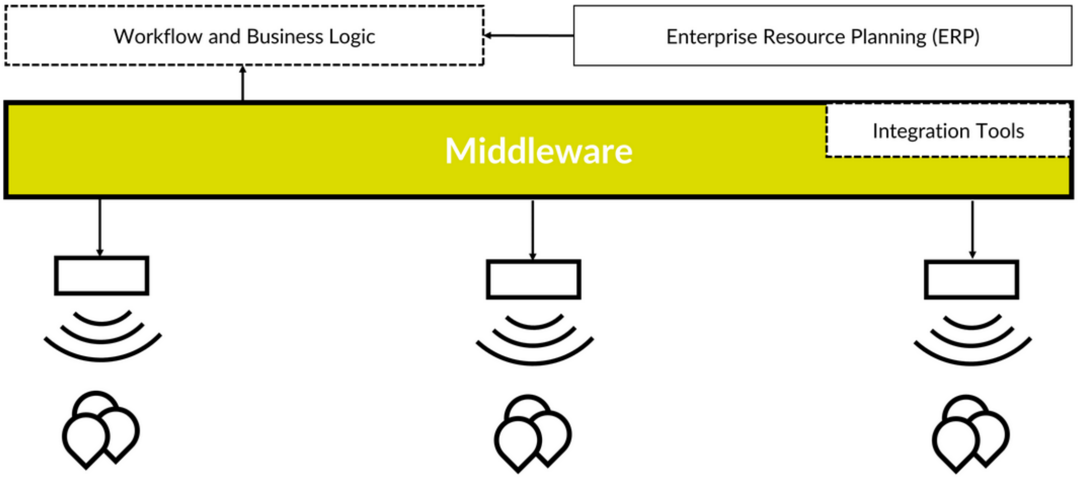


Figure 2. Typical use of RFID technology

The paper "A Hierarchical Model of the Impact of RFID Practices on Retail Supply Chain Performance" by Vlachos evaluates the impact of Radio Frequency Identification (RFID) practices on supply chain performance. It examines eight variables of RFID applications grouped in two categories: location (supplier's warehouse, retailer's central warehouse, retailer's local warehouse, retailer's owned stores) and utilization (standards, transportation, pallet level, specialized software). Given the inherent difficulty in assessing supply chain performance and the widespread use of different performance models, including SCOR and balanced scorecard, the paper develops a list of performance indicators. Results of this paper suggest that the implementation of RFID practices significantly affect the supply chain performance in the following areas: supplier, inventory, distribution, plan, sales, and forecasting. RFID can improve the performance of distribution systems, including products dispatched and inventory in transit by 33.8% and stock availability by 45.6%.

In the warehouse, the widespread adoption of pallet or item-level tagging — using low-cost, miniscule identification devices such as RFID — will pave the way for IoT-driven smart-inventory management. Let's examine a few instances of IoT in action in a warehouse. For starters, wireless readers capture data transmitted from each pallet as it arrives through inbound gateways. This data could include information on the product such as volume and dimensions, which could then be aggregated and sent to the WMS for processing. This capability eliminates the time-consuming task of manual counting and volume scanning of pallets. Cameras attached to the gateways could also be used for damage detection, by scanning pallets for imperfections. Once pallets are moved to the right location, tags transmit signals to the WMS to provide real-time visibility into inventory levels, thus preventing costly out-of-stock situations. If any item has been misplaced, sensors can alert the warehouse manager, who can track the item's exact location for corrective action. For quality management, sensors monitor the condition of an item and alert warehouse managers when the temperature or humidity thresholds are about to be compromised. This would allow warehousing staff to take corrective action, ensuring service quality and greater customer confidence.

During outbound delivery, pallets are scanned through an outbound gateway to ensure that the right items – in the right order for delivery – are being sent. Stock levels are then updated automatically in the WMS for accurate inventory control.

Beyond goods stored in a warehouse, IoT can also drive optimal asset utilization. By connecting machinery and vehicles to a central system, IoT enables warehouse managers to monitor all assets in real time. Managers can be alerted when an asset is being over-utilized or when an idle asset should be deployed to do other tasks. For example, a variety of sensors could be deployed to monitor how often assets in a sorting system, such as conveyer belts, are in use or idle, and at what times. Analysis of the data could then identify optimal capacity rates and tasks for the assets. One such innovation is Swisslog's "SmartLIFT" technology. The solution combines forklifts sensors with directional barcodes placed on the ceiling of the warehouse and WMS data to create an indoor GPS system that provides the forklift driver with accurate location and direction information of pallets. It also delivers a dashboard for managers to observe the real-time speed, location and productivity of all forklift drivers as well as visibility on inventory accuracy. Bobcat deployed the solution in its warehouse and reported a 30 percent increase in pallets per hour with no inventory errors.

2.2. Barcoding and optical recognition technology

Barcodes have been widely used in logistics for a long time. Most of 3PL companies have all necessary equipment to scan and store barcode information. The paper "Impact of Technology on Logistics and Supply Chain Management describes the ways of using barcoding and optical recognition technology during various warehousing operations like:

- **Procurement operation.** The parts and components brought from suppliers are assigned bar codes, which contain information on item name, batch number, date of manufacture, order no, serial no etc. The information in bar code helps in identifying and tracking the component. In the warehouse, when the goods enter through a conveyor, they are further scanned by the hand-held scanner or scanner fixed alongside the conveyor. The information decoded by the scanner is immediately logged in the central computer which helps real-time update of inventory records.
- **Processing.** During the order processing, the bar code will help in keeping identification of items based on their date of entry into the warehouse or store. This will ease material storage, retrieval and dispatch in FIFO (First in First out) inventory management system.
- **Production operation.** During the production process, the identification of in-process and finished items become easier due to barcoding. The various bathes at various stages of production can be easily tracked.
- **Distribution operation.** During the distribution, barcode helps in identifying and tracking the transit of finished goods to the customers.

2.3. Big Data and AI in logistics

The logistics sector is ideally placed to benefit from the technological and methodological advancements of Big Data. A strong hint that data mastery has always been key to the discipline is that, in its ancient Greek roots, logistics means "practical arithmetic". Today logistics providers manage a massive flow of goods and at the same time create vast data sets. For millions of shipments every day, origin and destination, size, weight, content, and location are all tracked across global delivery networks.

Many providers realize that Big Data is a gamechanging trend for the logistics industry. In a recent study on supply chain trends, 60% of the respondents stated that they are planning to invest in Big Data analytics within the next five years

Big data allows automated systems to function through intelligently routing many different data sets and data streams. For example, Amazon already has automation present in their fulfilment centres, which use little orange KIVA robots to grab items from shelves.

2.4. EDI communication

Electronic Data Interchange (EDI) is the computer-to-computer exchange of business documents in a standard electronic format between business partners.

The exchange of EDI documents is typically between two different companies, referred to as business partners or trading partners. For example, Company A may buy goods from

Company B. Company A sends orders to Company B. Company A and Company B are business partners.

EDI is a flexible way to integrate 3PL and client systems. It can support information flow for inbound, outbound, inventory adjustment, master data and many other data interfaces. On Figure 3 shown typical information flow between client ERP system and 3PL provider (Third party logistics).

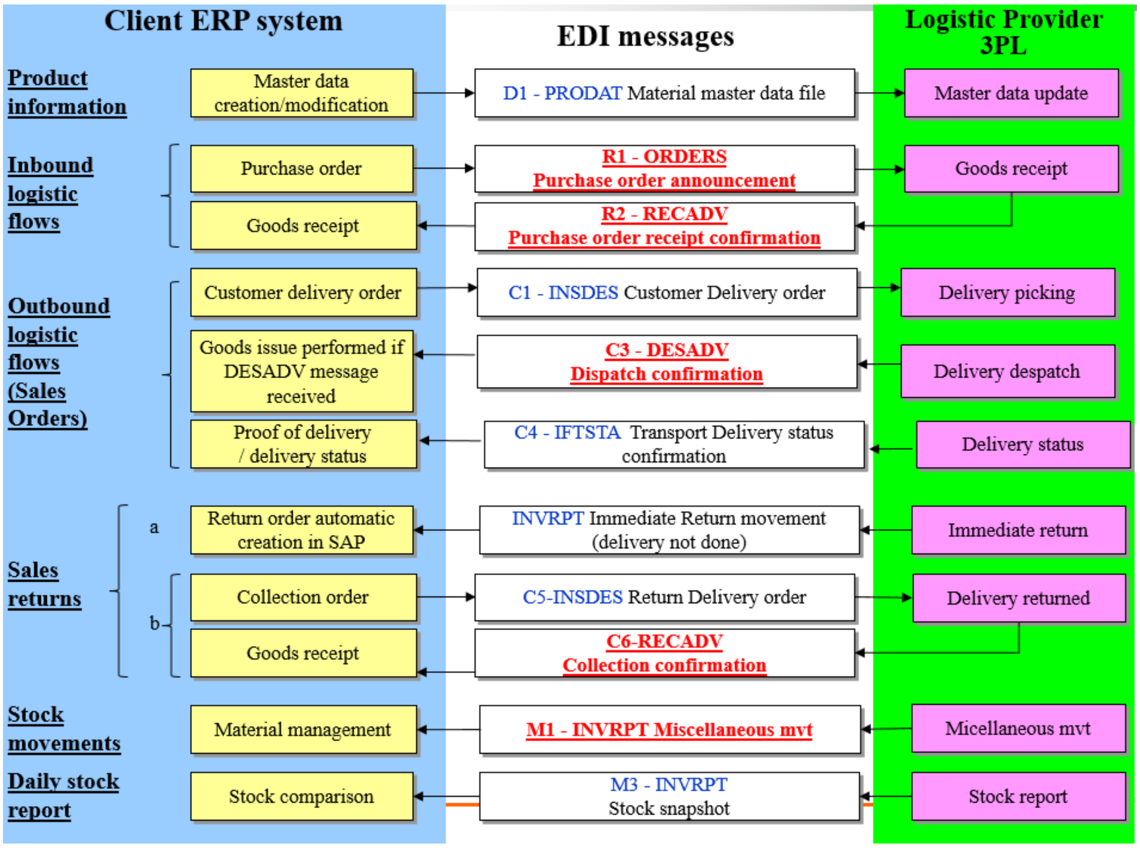


Figure 3. Information flow between client ERP system and 3PL provider

The benefits of EDI are:

- Quick process to information.
- Better customer service.
- Reduced paper work.
- Increased productivity.
- Improved tracing and expediting.
- Cost efficiency.
- Competitive advantage.
- Improved billing.

2.5. Genetic Algorithms. Travelling salesman problem

Evolutionary algorithms are the ones that follow the Darwin concept of “Survival of the fittest” mainly used for optimization problems for more than four decades (Holland, 1975).

Genetic algorithm (GA) is a search and optimization technique that mimics natural evolution. GA has already a relatively old history since the first work of John Holland on the adaptive systems goes back to 1962 (Holland, 1962).

Genetic algorithms are by nature adaptive optimization algorithms that mimic the process of natural selection and genetics (Goldberg, 1989).

In GA terminology, a solution x is called an individual or a chromosome. Chromosomes are made of discrete units called genes. The main operations of a GA are: selection, crossover and mutation.

The Travelling Salesman Problem or the TSP is a representative of a large class of problems known as combinatorial optimization problems (Greco, 2008). The problem with warehouse picking is very similar to TSP, as every picker picking goods for each order is like a salesman that needs to find the best route.

The most popular practical application of TSP are: regular distribution of goods or resources, finding of the shortest of customer servicing route, planning bus lines etc., but also in the areas that have nothing to do with travel routes (Brezina and Cickova, 2011).

3. Smart warehouse concept

Nowadays under "smart technology", most people consider processes automation. For sure automated picking, replenishment, inbound and outbound systems are indeed smart by today's standards. In my mind, "Smart warehouse" concept should include following key areas:

- Reasonable automation.
- Real-time data flow control.
- Flexible business processes and WMS software.

3.1. Reasonable automation

Smart Warehouses work to eliminate the use of manual labour and input wherever possible. In addition to helping reduce costs and manpower needs, process automation can increase accuracy and the speed in which data is input, no matter what level of volume is being processed.

It is not necessary to invest huge amount of money to get automation. In case of middle or even small size warehouses todays technologies can province solutions at an extremely affordable costs. For example, Advanced Shipment Notifications (ASNs), automated process execution, automated billing and more.

3.2. Real-time data flow control

Warehouse operations and IoT devices used on the warehouse generates a lot of data for analysis. Visibility and Real Time are the basic standards of any Smart Warehouse.

One of the many benefits to managing a smart warehouse is having real-time connection to the warehouse. The ability to receive immediate updates on all activity in a warehouse at any time makes it possible to monitor performance and ensure any issues are resolved quickly. With this information, businesses are better equipped to make improvements and optimize the process of the supply chain. This is not only beneficial for the company, but also for customers due to their growing desire to know where their order is at all times.

In the paper "Case Study of Improving Productivity in Warehouse Work" presented case study on how AI can help to increase picking efficiency by examining with Hitachi AI various types of Big Data generated by the warehouse operations and sensors. In their study after system implementation pickers work time was reduced and average of 8%.

Genetic algorithm calculation results in the paper "Genetic algorithm in comparison to ABC analysis for warehouse picking area layout calculation" (Avdeikins *et al.*, 2018) proves that use of AI in data analysis can reduce order picking costs up to 80 %.

3.3. Flexible business processes and WMS software

Flexibility in business processes and its implementation in the WMS software are the key success factors in 3PL's business. It should be easy adaptable to clients demands, reliable to be able to meet expectations from business side and highly customizable to be able to implement new and changed processes in due time. Loaded with high value features and functionality, WMS Solutions helps supply chain businesses boost productivity and efficiency and empower better decision making with real time operational data.

4. Conclusion

Essentially, a smart warehouse is right for every business — you just need to determine at what level of "smart" you need to be at to meet your current customer demand and plan for the future. Every business benefits from having a highly efficient warehouse that performs in a way that minimizes costs and error and maximizes organization and customer satisfaction.

A Smart Warehouse should be able to:

- Automate as it makes sense economically, but do not ignore the easy stuff. There is a lot of automation available here and now without any significant investment.
- Remain nimble in terms of space, staff and software.
- Scale instantaneously in response to need.
- Provide 100% Visibility in real-time.

References

1. Ahson, S. A., and Ilyas, M. (2008) *RFID Handbook: Applications, Technology, Security, and Privacy.* London, New York: CRC Press.
2. Avdeikins, A., Simakovs, A., Savrasovs, M. (2018) *Genetic algorithm in comparison to ABC analysis for warehouse picking area layout calculatio*n.
3. Brezina, I., Cickova, Z. (2011) Solving the Travelling Salesman Problem using the Ant colony Optimization. *Management Information Systems 6*, No. (4), PP. 010-014.
4. Case Study of Improving Productivity in Warehouse Work, *Hitachi Review, Vol. 65*, No.6 (2016)
5. Goldberg, David E. (1989) *Genetic algorithms in search, optimisation, and machine learning*. Boston, MA, USA: Addison Wesley Longman.
6. Greco, F. (2008) Travelling Salesman Problem. In-Teh is Croatian branch of I-Tech Education and Publishing KG. - http://www.exatas.ufpr.br/portal/docs_degraf/paulo/TravellingSalesmanProblem.pdf
7. Holland, J.H. (1962) Outline for a Logical Theory of Adaptive Systems. *Journal of the ACM*, 9, 297-314. - DOI - http://dx.doi.org/10.1145/321127.321128
8. Holland, J.H. (1975) *Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence*. Ann Arbor: University of Michigan Press.
9. Lieshou, M.V., Grossi, L., Spinelli, G., Helmus, S., Kool, L., Pennings, L., *et al*. (2007) *RFID Technologies: Emerging Issues, Challenges and Policy Options*. European Commission: Institute for Prospective Technological Studies.
10. *IOSR Journal of Business and Management* (IOSR-JBM). e-ISSN: 2278-487X, p-ISSN: 2319-7668, PP. 19-24.
11. Uckelmann, D. (2008) A Definition Approach to Smart Logistics. In: S. Balandin *et al*. (Eds): *NEW2AN 2008*, LNCS 5174, pp. 273–284, Springer, Berlin Heidelberg 2008.
12. Vlachos Ilias P. (2014) A hierarchical model of the impact of RFID practices on retail supply chain performance. *Expert Systems with Applications*, 41 (1), 5-15.

RESEARCH and TECHNOLOGY – STEP into the FUTURE

ISSN 1691-2853 & ISSN 1691-2861 (on line)

Supporting Organization:

Latvian Transport Development and Education Association
Latvian Operations Research Society

THE JOURNAL IS DESIGNED FOR PUBLISHING PAPERS CONCERNING THE FOLLOWING FIELDS OF RESEARCH:

- mathematical and computer modelling
- mathematical methods in natural and engineering sciences
- computer sciences
- aviation and aerospace technologies
- electronics and telecommunication
- telematics and information technologies
- transport and logistics
- economics and management
- social sciences

Articles and review are presented in the journal in English, Russian and Latvian (at the option of authors).
This volume is published without publisher editing.

EDITORIAL CORRESPONDENCE
Transporta un sakaru institūts (Transport and Telecommunication Institute)
Lomonosov 1, LV-1019, Riga, Latvia. Phone: (+371)67100594. Fax: (+371)67100535
E-mail: junior@tsi.lv, http:// www.tsi.lv

RESEARCH and TECHNOLOGY – STEP into the FUTURE, 2018, Vol. 13, No 2
ISSN 1691-2853, ISSN 1691-2861 (on-line: www.tsi.lv)

The journal of Transport and Telecommunication Institute (Riga, Latvia)
The journal is being published since 2006