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15-17 May, Beer-Sheva, Israel

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EDITORS' FOREWORD

I am pleased to present this proceeding of the 14th International Conference of Industrial Logistics (ICIL) 2018, which is taking place in Beer-Sheva, Israel during May 15-17. The conference was organized by the Department of Industrial Engineering and Management, the Faculty of Engineering Science, Ben-Gurion University (BGU) of the Negev in Beer-Sheva (Israel), the International Centre for Innovation and Industrial Logistics (ICIIL), and the Operations Research Society of Israel (ORSIS).

ICIIL is a nonprofit professional association, which has been developing an integrated view of Industrial Logistics, sharing and exchanging ideas and research results among students, researchers, academics and industrialists. The biannual International Conference on Industrial Logistics (ICIL) is the main mean to attain these objectives worldwide, moving from France 1993 to Brazil 1995, USA 1997, Russia 1999, Okinawa 2001, Finland 2003, Uruguay 2005, Lithuania 2006, Israel 2008, Brazil 2010, Croatia 2012 and 2014, and Poland 2016.

As presented in this proceedings book, the conference features a multidisciplinary program that includes original research results and contributions to the fields of logistics and supply chain management, related fields and their application.

Over 80 participants from 20 countries worldwide pre-registered to ICIL 2018. Twenty seven papers are included in this proceedings publication. We thank the organizing committee members and the Scientific/Reviewing Council members, who reviewed the papers. Each paper had at least two reviewers. We also thank the papers' contributors, the lecturers – 60, and especially the six well-known Keynote speakers.

Beer-Sheva is the capital of the Negev region – the Israeli desert. The Negev is the largest Israeli region in area (60%), but is the smallest in population. Recently, Beer-Sheva is becoming a vibrant modern city, with a population of 250,000 it is becoming a blooming city – an oasis in the middle of the desert, with many water fountains, refreshing the day and illuminating the night with their many colors.

The short guided tour of the city in the first evening gives us an overview of the combination of old and new in Beer-Sheva from the ancient and nomadic past desert to the most modern SyberSpark of BGU, at the nearby Advanced Technologies Park. Our evening tour ends at the old Abraham's-Well with a fascinating presentation of the story of the place and the region, followed by a reception organized for us by the city authorities.

In the second evening during the gala dinner, the VP of BGU, an archeologist, gives us a virtual tour of the ancient ruins of Biblical Beer-Sheva, which is situated few miles from the modern city.

The third day is devoted to a short visit in the impressive new logistic center of SodaStream about 15 km. from Beer-Sheva, and a longer fascinating tour of Jerusalem – Israel's capital, 100 km. furtherly.

We gladly invite professionals, academics, students and industrialists to utilize this conference both academically and socially. We hope that this publication will widen your horizon in logistics.

The Editors

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Invited Speakers

PROF. NICHOLAS G. HALL

RESEARCH AND TEACHING OPPORTUNITIES IN PROJECT MANAGEMENT

Short Bio:

Nicholas G. Hall is a Fisher College of Business Distinguished Professor, and has a courtesy appointment in the Department of Integrated Systems Engineering, at The Ohio State University. He holds a Ph.D. in Management Science (1986) from the University of California, Berkeley, as well as B.A., M.A. degrees from the University of Cambridge, and a professional qualification in accounting. His research interests are in project management, incentives, scheduling, and pricing, and applications of operations research. He has published over 80 articles in the journals *Operations Research*, *Management Science*, *Mathematics of Operations Research*, *Mathematical Programming*, *Games and Economic Behavior*, *Interfaces*, and several other journals. His main teaching interest is in project management. He has served for a total of over 40 years on the editorial boards of *Operations Research* and *Management Science*. He has given over 360 academic presentations, including 112 invited presentations in 24 countries, 11 conference keynote presentations, and nine INFORMS national conference tutorials. A 2008 citation study ranked him 13th among 1,376 scholars in the operations management field. He won the Fisher College Pacesetters' Faculty Research Award in 1998 and 2005. He has served as President of Manufacturing and Service Operations Management society (1999-2000), and as Treasurer of INFORMS (2011-2014). He has served on the State of Ohio Steel Industry Advisory Council (1997–2002). He has been a visiting professor at the Wharton School (University of Pennsylvania) and Kellogg School (Northwestern University). He is the owner of a consulting business, CDOR, which provides business solutions to the Ohio business and government communities, and advice on intellectual property issues to New York City law firms. In 2018, he is serving as the 24th President of INFORMS.

Abstract:

Almost one-quarter of the world's economic activity, with an annual value of $15 trillion, is organized using the business process of project management. This process has exhibited dramatic growth in business interest in recent years, with a greater than 1000% increase in Project Management Institute membership since1996. Contributing to this growth are many new applications of project management. These include IT implementations, research and development, software development, corporate change management and new product and service development. However, the very different characteristics of these modern projects present new challenges. The partial resolution of these challenges within project management practice over the last 20 years defines numerous interesting opportunities for academic researchers. These research opportunities make use of a remarkably broad range of methodologies, including robust optimization, cooperative and non-cooperative game theory, nonlinear optimization, predictive analytics, empirical studies and behavioral modeling. Furthermore, the $4.5 trillion that is annually at risk from a shortage of skilled project managers, and the 15.7 million new jobs in project management expected by 2020, provide great opportunities for contributions to project management education. These educational opportunities include the integration of case studies, analytics challenges, online simulations, in-class games, self-assessment exercises, videos and guest speaker presentations, which together form an appealing course for both business and engineering schools.

ELISE MILLER-HOOKS

OPTIMAL INVESTMENT FOR A RESILIENT GLOBAL PORT NETWORK

Short Bio:

Dr. Elise Miller-Hooks holds the Bill and Eleanor Hazel Endowed Chair in Infrastructure Engineering in the Department of Civil, Environmental, and Infrastructure Engineering at George Mason University. Prior to this appointment, Dr. Miller-Hooks served as Program Director (2014-2016) of the National Science Foundation (NSF) Civil Infrastructure Systems Program in the Engineering Directorate, lead Program Officer for the Critical Resilient Interdependent Infrastructure Systems and Processes (CRISP) solicitation, and a cognizant program officer on her division's Smart and Connected Communities (i.e. Smart Cities) initiative. She has also served on the faculties of the University of Maryland, Pennsylvania State University and Duke University. Dr. Miller-Hooks received her Ph.D. (1997) and M.S. (1994) degrees in Civil Engineering from the University of Texas – Austin and B.S. in Civil Engineering from Lafayette College (1992). She is an adjunct professor in Structural Engineering at Ben Gurion University. Her expertise is in: mathematical modeling and optimization for transportation systems; multi-hazard civil infrastructure resilience quantification; emergency/disaster planning and response; intermodal passenger and freight transport; real-time routing and fleet management; paratransit, ridesharing and bikeways; stochastic and dynamic network algorithms; and collaborative and multi-objective decision-making. Dr. Miller-Hooks serves on the editorial boards of *Transportation Science* (Associate Editor), *Journal of Intelligent Transportation Systems* and *Transportation Research Part B*, and is Chair of the TRB Transportation Network Modeling Committee, founding Co-Chair of the TRB Task Force on Emergency Evacuation, and past president of the INFORMS (Institute for Operations Research and the Management Sciences) Transportation Science and Logistics Society (TSL) and the Women in OR/MS Forum (WORMS).

Abstract:

Ports are critical components of the global supply chain, providing key connections between land- and maritime-based transport modes. They operate in cooperative, but competitive, co-opetitive, environments wherein the throughput of individual ports is linked through an underlying transshipment network. The ports, as well as supporting rail and roadway system infrastructures, however, are by the nature of their designs and locations inherently vulnerable to rising sea levels, significant precipitation events, storm surges and consequent coastal flooding. They are also subject to worker strikes as well as other disruptive events of natural or anthropogenic causes. Investments, thus, are needed to protect this intermodal (IM) system from such disruptive forces. This presentation proposes optimization and equilibrium techniques for developing multi-stakeholder, protective investment strategies aimed at enhancing resilience of this marine-based IM system to disruption while protecting the market share of individual ports. These techniques account for the existence of differing stakeholders, varying governing principles and variations in investment sources.

PROF. RETSEF LEVI

SYSTEMATIC RISK MANAGEMENT OF ECONOMICALLY MOTIVATED ADULTERATION IN FOOD SUPPLY CHAINS

Short Bio:

Retsef Levi is the J. Spencer Standish (1945) Professor of Operations Management at the MIT Sloan School of Management. He is a member of the Operations Management Group at MIT Sloan and affiliated with the MIT Operations Research Center. Before coming to MIT, he spent a year in the Department of Mathematical Sciences at the IBM T.J. Watson Research Center as the holder of the Goldstine Postdoctoral Fellowship. He received a Bachelor's degree in Mathematics from Tel-Aviv University (Israel) in 2001, and a PhD in Operations Research from Cornell University in 2005. Levi spent almost 12 years in the Israeli Defense Forces as an officer in the Intelligence Wing and was designated as an Extra Merit Officer. After leaving the Military, Levi joined and emerging new Israeli hi-tech company as a Business Development Consultant.

Levi's current research is focused on the design of analytical data-driven decision support models and tools addressing complex business and system design decisions under uncertainty in areas, such as health and healthcare management, supply chain, procurement and inventory management, revenue management, pricing optimization and logistics. He is interested in the theory underlying these models and algorithms, as well as their computational and organizational applicability in practical settings. Levi has been leading several industry-based collaborative research efforts with some of the major academic hospitals in the Boston area, such as Mass General Hospital (MGH), Beth Israel Deaconess Medical Center (BIDMC), Children's Hospital, and across the U.S. (e.g., Memorial Sloan Kettering Cancer Center, NYC Prebyterian Hospital System and the American Association of Medical Colleges). Levi was the PI on an MIT contract with the Federal Drug Administration (FDA) to develop systematic risk management approach to address risk related to economically motivated adulterations of food manufactured in global supply chains. With a multi-million award from the Walmart Foundation, Levi currently leads a multi-year U.S.-China collaborative effort to develop new predictive risk analytics tools and testing technologies and platforms to address core food safety challenges in China. Levi has also been involved in developing operational risk and process safety management methodologies for various organizations, in the healthcare, pharmaceutical and oil industries. Levi received the NSF Faculty Early Career Development award, the 2008 INFORMS Optimization Prize for Young Researchers, the 2013 Daniel H. Wagner Prize and the 2016 Harold W. Kuhn Award.

Levi teaches regularly courses on operations management, analytics, risk management, system thinking and healthcare to students from various degree and non-degree programs including MBA, Executive MBA, PhD, Master and Undergraduate students as well as Executive Education programs. His Healthcare Lab course attracts students from across the MIT campus and engages major industry partners and leaders. Levi has graduated 16 PhD students, 34 Master students and 6 postdoctoral fellows. He was also awarded several prestigious teaching awards.

Abstract:

Economically motivated adulteration (EMA) is a serious threat to public health. In this paper, we develop a comprehensive modeling framework to examine farms' strategic adulteration behavior and the resulting EMA risk in farming supply chains. We study both "preemptive EMA," where farms engage in adulteration to decrease the likelihood of producing low-quality output, and "reactive EMA," where adulteration is done to increase the perceived quality of the output. We fully characterize the farms' equilibrium adulteration behavior in both types of EMA and analyze how quality uncertainty, supply chain dispersion, traceability and testing sensitivity (in detecting adulteration) jointly impact the equilibrium adulteration behavior. We show that greater supply chain dispersion almost always leads to a higher risk of EMA. Furthermore, we caution that investing in quality improvement without also enhancing testing capabilities may inadvertently increase EMA risk. Our results offer tangible insights that can help companies and regulators to more proactively address EMA risk in food products.

PROF. YALE HERER

NEWSVENDOR: YOU HAVE MORE TIME THAN BEFORE

Short Bio:

Yale T. Herer, B.S. (1986), M.S. (1990), Ph.D. (1990), Cornell University, Department of Operations Research and Industrial Engineering. Yale is currently an Associate Professor in the Faculty of Industrial Engineering and Management at the Technion – Israel Institute of Technology. Yale joined the Technion in 1990 immediately after the completion of his graduate studies. In 1997 Yale moved to the Department of Industrial Engineering at Tel-Aviv University and in 2001 he returned to the Technion and has been there ever since. During the 2004-2005 academic year he spent a sabbatical at Northwestern University in the Department of Industrial Engineering and Management Sciences. During the 2011–2012 academic year he spent the fall semester on sabbatical at INSEAD in the Technology and Operations Management Area, and during the 2015–2016 academic year he was on sabbatical at the Georgia Institute of Technology. Yale also briefly visited Cornell University's Department of Operations Research and Industrial Engineering in the summer of 2000. He has worked for several industrial concerns, both as a consultant and as an advisor to project groups. Yale is a member of the Institute for Operations Research and Management Sciences (INFORMS) and the Operations Research Society of Israel (ORSIS). He currently serves as vice president of ORSIS. He also serves as an Associate Editor for *Naval Research Logistics* and has served on the editorial staff of *IIE Transactions* and {*Operations Research Letters*. Yale has successfully planned and executed three conferences. In 2006 he chaired the national conference for ORSIS. In 2010 he chaired the annual conference for the Manufacturing and Service Operations Management Society (MSOM) of INFORMS. MSOM is the largest subdivision of INFORMS. Finally Yale co-chaired an POMS Israel 2017.

Yale's research interest can be broadly defined as covering Production Planning and Control. More recently Yale has focused his research on the area of Supply Chain Management, especially when integrated with transshipments or other responsive operational activities. Yale has won various prizes including a 1996 *IIE Transactions* Best Paper Award, the 2002 Mitchner Award in Quality Sciences and Quality Management, a 2008 IBM Faculty Award, and INFORM's 2013 Daniel H. Wagner Prize for Excellence in Operations Research Practice.

Abstract:

The world is being transformed by technology. The Newsvendor Problem, one of the cornerstones of Supply Chain Management (inventory management really), is no exception. Though there are many ways that technology is affecting the Newsvendor Problem, we will concentrate on exploring two such ways: inventory accuracy and slowing down time. Though we will mention the new technologies, our talk will focus on new newsvendor type models that have come about due to the new technology. In particular, we will examine our new newsvendor models and associated case studies.

ANDRES WEINTRAUB

OPERATIONS RESEARCH SYSTEMS SUPPORT LOGISTIC DECISIONS

Short Bio:

Andres Weintraub holds a degree in Electrical Engineering from the University of Chile a Masters in Statistics and a Ph.D. in Industrial Engineering and Operations Research from the University of California, Berkeley. He is a Professor at the Department of Industrial Engineering, University of Chile. His main research areas are Operations Research, Operations Management in forestry and mining, logistics and transportation.

He has published over 70 papers in recognized journals, including Operations Research, Management Science, Forest Science, the European Journal of Operations Research. He has also edited several books and journal issues on topics related to use of Operations Research in natural resources. He has carried out multiple projects with industry and governmental organizations, including the US Forest Service and forest firms in Chile in models related to long range planning, short term harvesting and transportation, CODELCO, one of the largest copper firms in the world in models related to long range copper extraction, logistics and production planning for the salmon industries, CSAV, a top 10 worldwide shipping company, housed in Chile, to improve the management of their 500.000 container business, the Chilean Ministry of Education, on determining best locations of rural schools, and the Chilean Football Association in scheduling the football season since 2005. The work with Chilean forest firms won the Edelman Prize, the most prestigious award for applied Operations Research, awarded by INFORMS, the US Society for Operations Research and Management Sciences. The work with CSAV was an Edelman finalist in 2011 and the football scheduling was a finalist in 2016.

He has received many recognitions which include: The Chilean National Prize for Applied Science in 2000, the Harold Larnder Prize given by the Canadian OR Society, the INFORMS Presidential Prize, the Gold Medal from the Chilean Institute of Engineering, its highest recognition. He was awarded a Doctor Honoris Causa, from the University of Agricultural Sciences of Sweden, and the University of Laval, Canada. He is a member of the US National Academy of Engineering, and the Chilean National Academies of Science and of Engineering and is INFORMS Fellow.

He was a founder and former President of ALIO, the Latin American Association of OR, and President of IFORS, the International Federation of Operations Research Societies, which includes over 50 country members, for the years 1998 to 2000.

He has led for the last 10 years the Institute for Complex Engineering Systems, which is currently funded yearly with 3 million dollars, and involves 60 researchers and a staff of 15 people. The Institute covers areas such as Operations Research, Data Science, Industrial Organization and Consumer Analytics. The Institute is strong in developing projects with industry and the government which are original and have impact. These projects have had high impact and led to a large number of publications.

Abstract:

Our group has a stated objective: to develop innovative, high impact projects for Chilean firms and public institutions. Systems, based on Operations Research methodologies that should change the way firms operate. This talk presents several of the projects we have developed in the area of logistics. I discuss the problems the firms had, the methodology we developed and the impact of the implementation. The cases are in the areas of forest timber transport, scheduling movement of empty containers for a large shipping company, transportation in the salmon production chain, and how fire trucks are scheduled to arrive faster to contain fires. These systems have led to important savings and improvements in operations in each case.

PROF. TADEUSZ ZAWIK

SUPPLY CHAIN DISRUPTION MANAGEMENT USING A MULTI-PORTFOLIO APPROACH

Short Bio:

Tadeusz Sawik is a Professor of Industrial Engineering and Operations Research at AGH University of Science and Technology in Kraków, Poland. He received the MS degree in mechanical engineering, the PhD degree in automation engineering and the ScD (habilitation) degree in operations research, all from AGH University. He has been a visiting professor in Germany, Japan, Sweden and Switzerland and he has served as a research advisor of Motorola for several years. He is also a five-time recipient of the Scientific Excellence Individual Award from the Minister of Science and Higher Education, one of the most prestigious award in Poland, and over 25-time from the Rector of AGH. Professor Sawik works in the area of logistics and supply chain management, with a particular recent focus on supply chain risk management. He is the first researcher to apply the financial engineering percentile risk measures, Value-at-Risk and Conditional Value-at-Risk in the context of supply disruptions and one of the first researchers who investigated multi-level (partial) disruption risks. His current research interests also include cybersecurity and homeland security. He has published numerous books (including *Production Planning and Scheduling in Flexible Assembly Systems*, Springer, 1998, *Scheduling in Supply Chains Using Mixed Integer Programming*, Wiley, 2011 and *Supply Chain Disruption Management Using Stochastic Mixed Integer Programming*, Springer, 2018), and more than 150 individual articles in refereed journals, including Highly Cited papers in Economics & Business of the Thomson Reuters Essential Science Indicators database. In the 50th and 55th volume anniversary issue of *International Journal of Production Research,* he has been recognized as one of the leading scholars in Production Research. He is the founding Editor-in-Chief of *Decision Making in Manufacturing and Services* (AGH University Press).

http://home.agh.edu.pl/~tsawik

Abstract:

A new portfolio approach is presented to support decision-making in the presence of supply chain disruption risks. Unlike most of reported research on supply chain disruption management, a disruptive event is assumed to impact both a primary supplier of parts and the buyer firm's primary assembly plant. Then the firm may choose alternate (recovery) suppliers and move production to alternate (recovery) plants along with transshipment of parts from the impacted primary plant to the recovery plants. For the impacted suppliers and assembly plants, both time and cost of recovery from disruption is considered. The resulting allocation of unfulfilled demand for parts among recovery suppliers and unfulfilled demand for products among recovery assembly plants determines recovery supply and demand portfolio, respectively. Scenario-based stochastic mixed integer programming formulations with an embedded network flow problem are developed for selection of primary suppliers; the decision to be implemented before a disruption and for selection of recovery suppliers and recovery assembly plants,; and the decision to be implemented during and after the disruption. Local and regional, two- and multi-level disruptions of suppliers and assembly plants are considered. The selection of supply, transshipment and demand portfolios is determined simultaneously with production scheduling

in assembly plants. The two decision-making approaches will be considered: an integrated approach with the information about the future disruption scenarios, and a hierarchical approach with no such information available ahead of time. In the integrated approach a two-stage stochastic model is applied, in which the first stage decision considers disruption scenarios to happen in the second stage, so that the impact of disruption risks is mitigated. The second stage decision optimizes the supply chain recovery process. The integrated approach accounts for all potential disruption scenarios. The primary supply portfolio that will hedge against all scenarios is determined along with the recovery supply and demand portfolios and production schedule of finished products for each scenario. In the hierarchical approach, first the primary supply portfolio is selected to optimize supplies and production in deterministic conditions (without a disruption), and then, when a primary supplier or primary assembly plant is hit by a disruption, the recovery supply and demand portfolios are determined along with transshipment of parts and production schedule at recovery plants to optimize the process of recovery from the disruption, given the unfulfilled demand for products and the inventory of parts at the primary assembly plant. The integrated decision-making selects a more diversified primary supply portfolio to hedge against all potential disruption scenarios. When all primary suppliers are completely shut down, a single sourcing recovery supply portfolio is usually selected. If all assembly plants are shut down, the integrated approach may select the primary plant as a single recovery plant, whereas the hierarchical approach may choose multiple recovery plants. The scenario analysis indicates that for the hierarchical approach the best-case and worst-case disruption scenarios are, respectively, subsets and supersets of the corresponding scenarios for the integrated approach. In addition to risk-neutral decision-making based on expected cost or expected service level optimization, an integrated risk-averse approach is developed using Conditional Value-at-Risk as a risk measure. Several modifications of the proposed portfolio approach will be discussed, including selection of a resilient supply portfolio with fortified suppliers and prepositioning of emergency inventory of parts and selection of a dynamic supply portfolio under delay and disruption risks. A multi-period stochastic formulation will be compared with a simplified two-period model, where the multi-period production decisions are replaced by a simplified two-period decision: production before and production after a disruptive event. Computational results will be presented and discussed. The findings indicate that the developed multi-portfolio approach leads to computationally efficient mixed integer programming models with a very strong LP relaxation.

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Conference Papers

RESEARCH TRENDS ON INDUSTRIAL LOGISTICS

Gabriel Aguiar de ARAUJO, Maria Cristina Fogliatti de SINAY

University of Grande Rio – UNIGRANRIO, Posgraduation Program in Management Lapa, 86, Lapa – Rio de Janeiro/RJ – Brazil

Abstract

The purpose of this article is to verify the trends and interrelations between the various subtopics of the Logistics area of knowledge. In order to do so, an analysis of the co-occurrences of keywords in academic articles was performed. Data from the Web of Science database were divided by decade (from 1951 until 2017) and treated with Vosviewer software. An exponential growth of the field from the year 2000, with a tendency to stagnation by 2017 was observed. Themes that were relevant in the past have been replaced by new themes of interest and increasingly new themes are addressed.

Keywords: *industrial logistics, science development, trends*

1. INTRODUCTION

A central question that pervades human development is the ability to store and share generated knowledge since this is the base for all the decisions to be made. Thus mankind is perfect, expanding the generated horizons of possible experiences to each generation and knowledge inexorably grows and also evolves.

Nowadays, scientific activity is seen as a process of production of scientific knowledge on a large scale. This activity is developed through the publication of articles, books and journals[1], in an increasingly accelerated way, making it necessary to evaluate this progress both quantitatively and qualitatively[2]. In this sense, several methodologies were developed to meet these objectives[3].

Part of these studies gave rise to a field of research known as Sociology of Science[1], focusing on the interdependence relationship between a certain type of knowledge and the social structure that involves it[4]. Corroborating this idea, Borner et al.[5] and Fagan[6] argue that groups are necessary for the production of scientific knowledge both qualitatively and quantitatively. Such phenomenon was observed by Vargas-Quesada et al.[7] as being responsible for the interconnectivity of the various fields of science, making its structure similar to a network.

Sociology of science analyzes the social phenomenon in structural terms, that is, it does not focus on the individual participation of each researcher, but rather on their interaction and influence in the group. Studies in this sense are known as social network analysis[8].

Each scientific field has peculiarities, so it is recommended the understanding of the differences and similarities between them. As the keywords synthesize the main ideas present in the academic works, their analysis makes it possible to identify the peculiarities and tendencies of certain field of knowledge, as well as the networks of related ideas, interconnected through co-occurrences in academic articles.

Human development has always depended on logistic functions. After the industrial revolution, and more recently after the information revolution, the development of effective logistics systems has become an imperative condition for the survival of societies and organizations. As one of the main objectives of science is to seek solutions for practical life, several researchers have specialized in studying the phenomena that make up the field of knowledge known today as logistics.

Thus, the purpose of this article is to verify the trends and interrelations between the various subtopics of this area of knowledge. In order to achieve this objective, after selecting specific keywords related to industrial logistics, an analysis of co-occurrences between selected keywords in academic articles was performed. The results of this analyses clearly shows the trends of this field of study.

2. RESEARCH METHODS

The universe of this research encompasses all the academic knowledge about logistics generated and published in scientific journals from 1951 to 2017. The sample is composed of scientific articles published in periodicals that belong to the main collection of the database known as Web of Science (WoS) of Clarivate Analytics Company.

The choice of this database was due to its scope and quality. Other bases and models of documents, eg. books, conference papers, etc., were not used due to the possible disregarding of their outputs, besides the possible repetition of contents. WoS has documents published since 1945, distributed in more than 18,000 periodicals. The more than 1.3 billion citations date back to the beginning of the 20th century. These characteristics, coupled with editorial policies that demand neutrality and quality from the editors of the participating journals, make the database a reliably and suitable multidisciplinary tool for the proposed study.

Data collection was performed on 11/01/2018 by searching the database, using the search tool available in it. The files with the academic texts were not downloaded. Only the information that allow the use of the tools employed in this work was obtained. The articles were selected by searching for the term “logistics” in the titles, abstracts or keywords of them. As the scope of work is industrial logistics, only articles related to business administration were selected.

Data were divided by decade and treated with Vosviewer software (version 1.6.5), free software that can be used to construct several types of maps, considering authors, periodical institutions and keywords as actors[9].

The most widely used technique for making distance-based maps is the multidimensional scale. However, Van Eck and Waltman[10] presented VOS as a new technique. The VOS was developed to locate items in space such that the distance between two items reflects the similarity or ratio of items as accurately as possible. Thus, it minimizes, through a variant of the SMACOF[11] algorithm the weighted sum of the square distances between all pairs of items. This quadratic distance between a pair of items is weighted by the similarity between items. To avoid solutions where all items have the same location, a constraint is imposed so that the average distance between two items equals one. The mathematical and detailed explanation of the technique can be obtained in the works of Van Eck et al.[12] and Van Eck and Waltman[9,10].

With this tool, maps were obtained where the keywords that appear in the same article, generate links. In this way, the more articles in common the keywords have, the greater the strength between their links. In addition to the strength of the links, graphically indicated by the thickness of the trace that connects them on the map, the software employed provides a division by groups, based on the affinity between the keywords, considered the actors of the network.

3. ANALYSIS

In this session the results of the work are presented and analyzed. Figure 1 shows the number of articles collected according to the year of publication. It is observed an exponential increase in the number of publications from the year 2000. Such quantitative increase can show the relevance that the theme achieved with the increase of the commercial needs in function of the demands of the globalization.

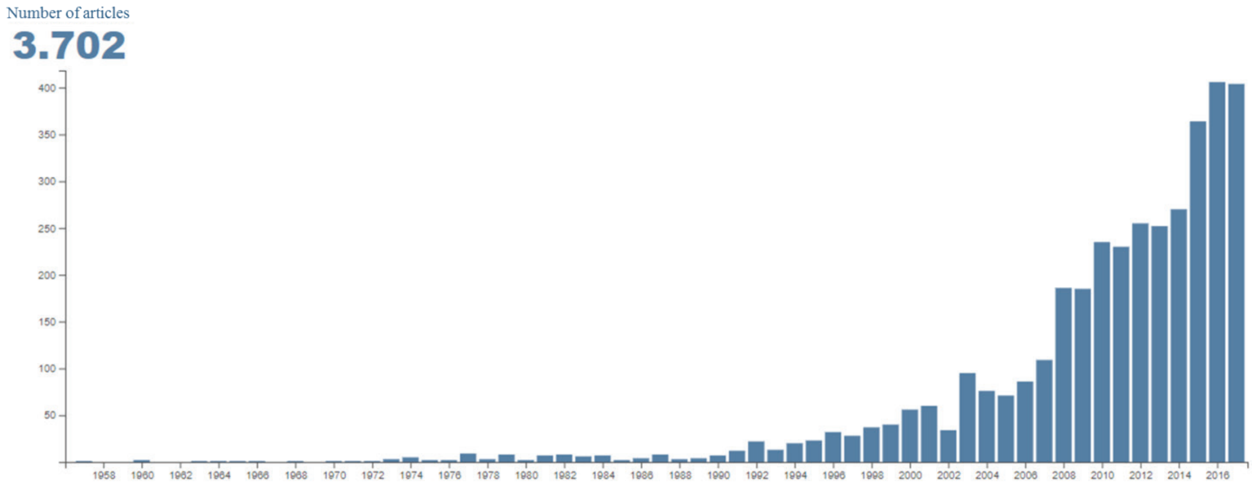

Figure 1 – Number of articles

Table 1 presents the results of the performed analyzes on the keywords. As already mentioned, there is an exponential growth in the number of publications and, consequently, in the number of keywords from the year 2000 up.

The keyword logistics appears as the main keyword in all decades analyzed. Due to the type of search performed, this result was expected. However, it is observed a reduction of the percentage of participation of occurrences of this keyword over time, indicating that other expressions are also becoming relevant.

In the decade of 1991-2000 subjects such as distribution, inventory and manufacturing responded as relevant keywords, indicating the main topics of interest to the researchers. In the following decade, 2001-2010, supply chain management, distribution management and reverse logistics already presented themselves as more relevant subjects. The manufacturing theme is no longer on the list for that decade. In the period of 2011-2017, supply chain management and reverse logistics remain relevant, despite the reduction in percentages, but the keywords humanitarian logistics and sustainability stands out as relevant. In this decade, the keyword distribution management lost strength as a research topic and appeared last in the list. Another topic observed in Table 1 is the greater homogeneity of the keywords over time. The significant increase of articles related to the field did not mean concentration of publications on central themes, but rather its spraying

These changes in the field main topics may indicate trends that could be used by businesses and by scholars. To the firsts, as indicators of technology development needs or operational changes needs and to the latter, as a pointer of the capacity of innovation of the generated knowledge.

Table 1 – Keywords Analysis

Decade	**51-60**	**61-70**	**71-80**	**81-90**	**91-00**	
Number of Articles	3	6	36	56	283	
# Keywords	N/A				508	
Top 10 Keywords	N/A				Logistics	10,2%
					Distribution	2,6%
					Inventory	2,0%
					Manufacturing	1,8%
					Transportation	1,6%
					Decision support systems	1,2%
					Mathematical programming	1,0%
					Military	1,0%
					Neural networks	1,0%
					Supply-chain management	1,0%

Decade	**01-10**		**11-17**	
Number of Articles	1137		2181	
# Keywords	2497		6006	
Top 10 Keywords	Logistics	7,4%	Logistics	4,2%
	Supply chain management	6,7%	Supply chain management	4,0%
	Distribution management	2,5%	Reverse logistics	1,6%
	Reverse logistics	2,1%	Humanitarian logistics	1,2%
	Inventory	1,4%	Supply chain	1,1%
	Transportation	1,4%	Sustainability	1,1%
	Outsourcing	1,2%	Innovation	0,8%
	Supply chain	1,2%	China	0,7%
	Distribution	1,0%	Transportation	0,7%
	Simulation	1,0%	Distribution management	0,6%

Figure 2 shows the co-occurrence network of keywords formed when two keywords are in the same article. The more the same keywords are present in the articles, the greater the strength of the link between them. The size of the actors in the figure indicates the number of times these keywords occur in the total period from 1951 to 2017.

As already mentioned, logistics and supply chain management play central roles in the field. However, the image brings the dimension of the connections of each of these themes. There are four main groups indicated by blue (logistics), red (supply chain management), purple (transport and pricing) and yellow (innovation). The main keywords associated with the first group are distribution, optimization and scheduling. For the second group, the main keywords are China, Europe, trust and benchmarking. For the third group, gender, healthcare and global manufacturing stand out. The keywords associated with the latter group are entrepreneurship and performance-based logistics. This graph allows evaluating the more global relationship that the various topics related to logistics have. It stands out the enormous amount of terms, their relations and the plurality of them.

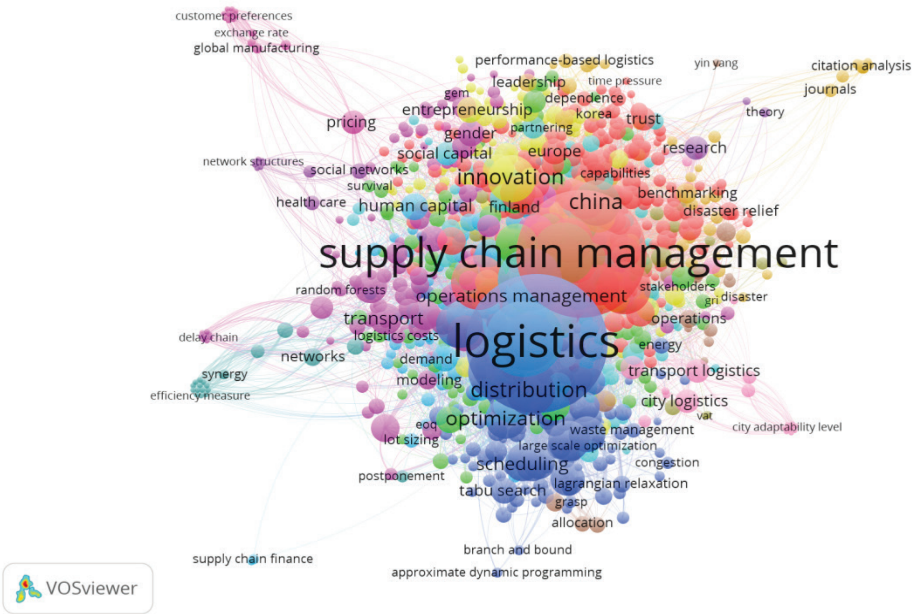

Figure 2 – Co-occurrence of keywords

4. FINAL REMARKS

The purpose of this paper was to evaluate trends in logistics research and to identify relationships among its subtopics. It was observed an exponential growth of the field from the year 2000 up with tendency to stagnation by 2017.

Themes that have been relevant in the past have been replaced by new themes of interest and increasingly new themes are addressed, indicating a relative loss of hegemony of some relevant topics to emerging new topics.

The subtopics could be grouped according to the joint appearance in the articles. The evolution of the themes was corroborated, with the appearance of smaller groups related to pricing, global manufacturing, innovation and entrepreneurship. In a short period of time, these new topics can become relevant in this research field.

For future research, it is suggested to observe the quantitative of publications and to identify new research tendencies.

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OPTIMAL ROAD PROJECT PORTFOLIO SELECTION UNDER LIMITED LOCAL AUTHORITIES' BUDGETS IN POLYNOMIAL TIME

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Abstract

In most cases of road project portfolio selection, a limited budget is spent to build the best subset of a large set of possible road links. This paper tackles a special case where budgets of local entities located in the same geographical area of an authority that tries to optimize the selection of a road projects' subset. The non-polynomial complexity of existing formulations is prohibitive and dictates the use of search techniques for solutions. The technique uses a transfiguration of the problem into a minimum cost network flow problem which ensures optimal solution in polynomial time.

Keywords: *transportation, binary variable optimization, maximal flow optimization, transportation management, project selection*

1. INTRODUCTION

Government transportation agencies are faced with the problem of efficiently selecting a subset of road construction projects for implementation. The transportation projects selection problem has been considered by a large number of studies (e.g., [1,2]). There is a broad variety of mathematical programming models having a wide range of assumptions regarding the required budget (or other) resources, the costs and estimated utilities of the road projects, as well as the overall budget. Each model is suitable to a specific type of cases.

In most models, it is assumed that a single budget is given and partly or wholly allocated to the potential road construction projects. This problem is often described as a version of the knapsack problem. The proposed model is somewhat different. In the problem described in this paper, each potential road link, is running between two different local authorities (or cities, or regions, or boroughs) that directly benefit from it, and so have to share the construction and maintenance costs of the road link. Each potential road link is represented by an arc on a network, where the endpoints of the arc are the local authorities (or cities, or regions, or boroughs). Each road link can be either constructed or not at a given cost. Each local authority carries a budget which can be allocated only to road links that connect it with other local authorities. Thus, cost of a specific road link can be budgeted only by the local authorities connected to the road link (typically two local authorities) – although such budget does not have to be evenly allocated by the two local authorities. An expected value, or benefit, is associated with each potential road link, for each of the local authorities connected by it, regardless of the budget allocated by it. The objective is to maximize the overall benefits to the local authorities by constructing a set of road projects. Three forms of road projects may be considered in a portfolio of potential road construction project: independence, complementarity and substitution [3]. Complementary projects can enhance performance of overall objectives, while substitutive projects can only substitute, but not increase, objective performance. In this work, it is assumed that all the potential road projects have independent costs and independent benefits, thus the overall costs of all selected road projects, and their overall benefits, are equal to the aggregated costs of the selected road projects and their aggregated benefits, accordingly. The problem presented in this work can be extended to include complementarity and substitution forms of road projects, but such an extension is not in the scope of the present work.

2. MODEL DESCRIPTION

Nomenclature

i, j	indexes of local authorities connected by a potential road link (end points) (where *n* is the total number of local authorities)
B_i	The budget of local authority *i* for new road construction
d_i	The number of candidate road links that coincide with (connect to) local authority *i*
C_{ij}	The cost of potential road link between two local authorities: *i-j*
V_{ij}	The expected value or benefits for local authority i from the construction of a road link between two local authorities: *i-j*
R_{ij}	The remaining payment of local authority *i* after its neighboring authority *j* paid it lower bound share for link ij construction
X_{ij}	A binary decision variable having a value of 1 if roadlink *i-j* is selected for construction and 0 otherwise

2.1. The binary variable optimization formulation

In order to build a practical model we convert part of the information into a single dimension of monetary value. The budget of a local authority *i* is already given in terms of monetary value (B_i). Moreover the construction costs of a road link between two local authorities *i* and *j* are also given in terms of monetary value (C_{ij}). The benefit values of a road link *ij* to local authority *i* are allocated to V_{ij}. Also, the effect of the distance, and traffic density, would be included in V_{ij}. Each road link contributes to both its ends, but its cost should be counted only once. Therefore, the objective function is the sum over all constructed road links of their values (V_{ij}+ V_{ji}) minus their costs (C_{ij}). In addition, each local authority *i* must abide by its budget for that matter. For the binary formulation our major work assumption is that the local authorities divide their budget evenly between their emanating road links. Taking the conservative stance, the lower bound on the budget for each selected emanating road is the local budget divided evenly between all possible emanating road projects (not all of them are necessarily chosen). However, the road link is financed by the two local authorities on the road's end-points. Thus, the neighboring local authorities participate in financing their connecting road link. The minimum/lower-bound pre-dedicated budget for local authority *j* is computed by dividing their budget equally according to their degree (d_j = number of emanating arcs from node *j*). Therefore, the road construction cost remaining for local authority *i,* after taking the lower-bound from the neighboring local authority *j* is:

$$R_{ij} = Max\left\{\left(C_j - \frac{B_j}{d_j}\right), 0\right\} \tag{1}$$

In (1) the cost is taken to be zero in cases where lower bound budget of the neighbor covers more than the road link costs. Thus, the proposed model is of the form:

$$Z = MAX : \sum_{i=1}^{n} \sum_{j=i+1}^{n} \left(V_{ij} + V_{ji} - C_{ij}\right) X_{ij} \tag{2}$$

$$s.t.$$

$$\sum_{j=1}^{n} R_{ij} X_j \le B_i \tag{3}$$

$$X_{ij} = \begin{cases} 0\_road\_link\_ij\_is\_not\_selected \\ 1\_road\_link\_ij\_is\_selected\_ \end{cases} \tag{4}$$

The above formulation maximizes the overall benefits while minimizing the costs and the constraints are such that all roads emanating from each local authority *i*, would cost less than its budget. The total number of binary variables (the X vector) is limited by *n*(*n*-1)/2, and the number of possible solutions is thus:

$$2^{\left(\frac{n(n-1)}{2}\right)} \tag{5}$$

The benefit of building a road link is primarily related to the added direct connection between the two relevant local authorities – represented by the link's end points. Note that for evaluating the links contribution the model sums both V_{ij} and V_{ji}, and since these values are preprocessed, the model allows cases where one end point benefits more than the other end point. Thus, a cost is associated with a road link C_{ij} and benefits are associated with its two end points: V_{ij} and V_{ji}. Since the formulation has the general form and structure of a knapsack problem, and since knapsack problems have non-polynomial complexity (NP) [4,5], the proposed formulation (1) is also NP-hard. Moreover, the budget and costs are connected in the constraints based on somewhat artificial assumption on evenly divided budget pre-dedicated to each possible emanating road link. The budget-cost network model, described in the next section, while simpler, treats complexity and budget-cost relationships better, and its solution is obtained through the well-known Minimum Cost Network Flow (MCNF) model.

2.2. A numeric example: The budget-cost network model

The budget-cost network model is simple: it involves only budgets (on nodes) and costs (on arcs). The budget-cost network model starts with modeling the physical network as a network of edges and vertices: (*E, V*) where local authority construction and maintenance costs are attached to edges (*E*) and the budgets are attached to vertices (*V*). An example network with the local authorities' budgets and the road link costs is depicted in Figure 1.

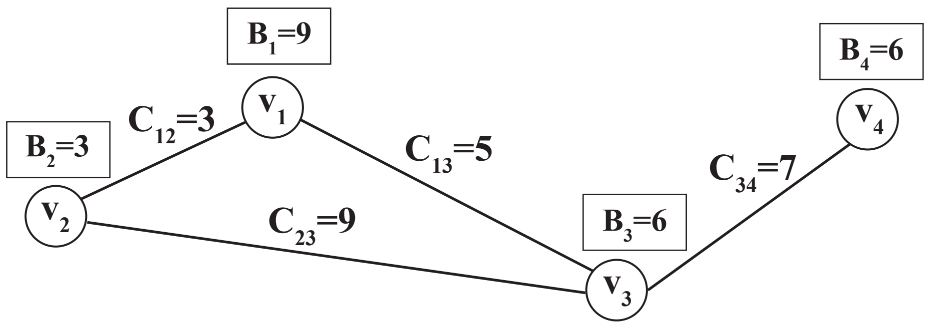

Figure 1 – A set of potential road links with their costs (C_{ij}) on edges, and budgets (B_i) on vertices

2.3. Transformation of the network into a network flow problem

We now show how this problem could be translated into an equivalent network flow problem. The vertices (local authorities) are arranged on left side of a bipartite graph and the edges (road links) are arranged on the right side of the bipartite graph as shown in Figure 2. The next step is to draw arrows between the vertices and their corresponding edges (the potential road projects that have the node as one of its end-points). Finally, the budget limit of each local authority is allocated to the vertices, and the road link's costs on the edges side. An example of the bipartite graph is shown in Figure 2.

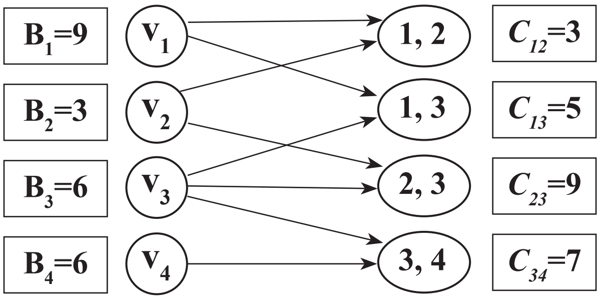

Figure 2 – An example of a bipartite graph with budgets on vertices' side, and the road link costs on the edges' side

The second stage of the transformation is connecting the two sides of the bipartite graph to a source node s and a sink node t. The arcs between the vertices and edges are assigned infinite capacity. The corresponding example continues in Figure 3.

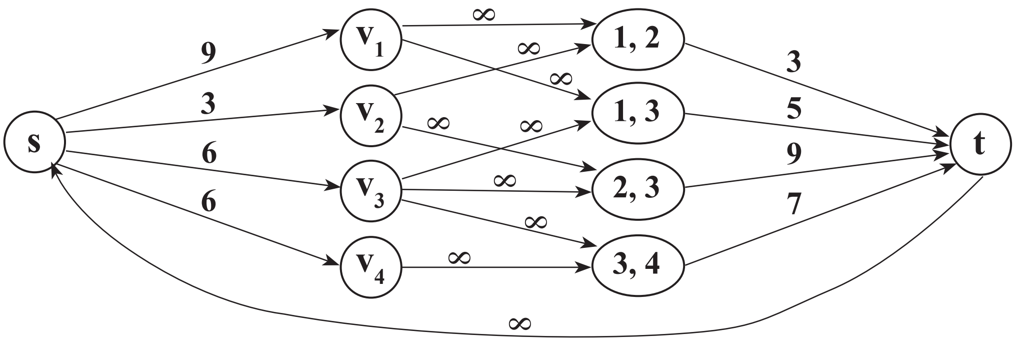

Figure 3 – The full network flow model for the budget-cost network example

Figure 3 shows the budgets as sources of flow on the left side, the money flows to the right side to pay for the construction costs of the various road link projects. The overall objective is to maximize the flow. This is easily measured as max flow on the link *s*-t [6]. This problem is known to have polynomial time solution [7]. This could be easily verified since the problem's constraints are based on the node-arc incidence matrix. The optimal solution for the maximal flow problem is depicted in Figure 4.

Figure 4 shows that the costs of road links (1,2) (1,3) and (3,4) are fully covered by the budgets, while road link (2,3) is not fully covered, and therefore cannot be executed. Figure 4 also shows that the budget of local authority 4 is fully utilized, local authority 1 spends 6 out of budget of 7, and local authority 3 spends 1 out of budget of 5. Since no new roads are allocated to local authority 2 it spends none of its budget.

Figure 5 depicts the road link selection and budget usage implied by Figure 4.

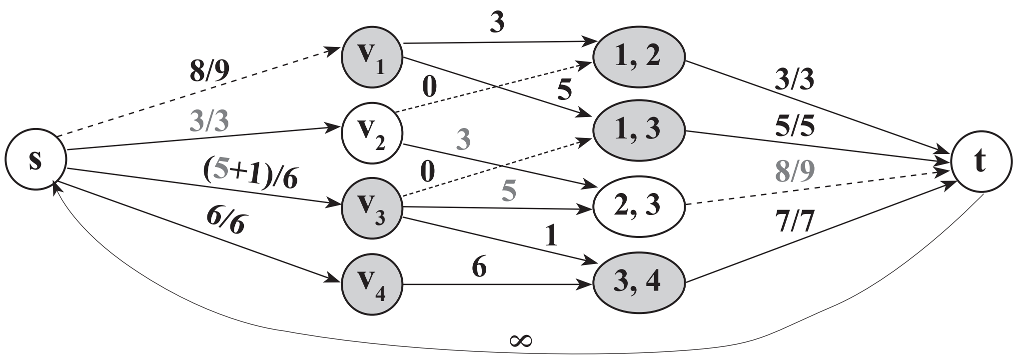

Figure 4 – A max flow solution of the set of potential road links with their costs (C_{ij}) on edges, and budgets (B_i) on vertices.

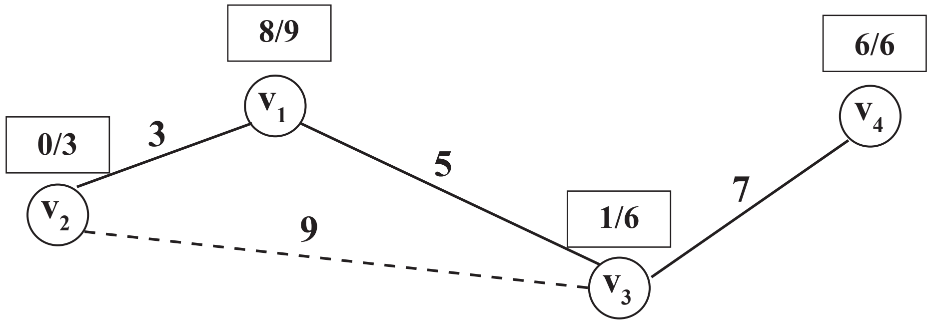

Figure 5 – The maximum flow solution: Set of road links for construction and the road link not chosen (hatched line)

3. CONCLUSIONS

This paper presented the situation where the budgets of local authorities are allocated for building new road projects, in a defined region where an overall regional construction plan is to be made. Each budget must be assigned to road projects that are connected to the corresponding local authority. An optimization model with binary decision variables was presented based on simultaneously maximizing the benefits and minimizing the costs while keeping within budget. A second model based on budgets costs was presented along with its conversion process into a maximal flow optimization. Since maximal flow problem is known to have polynomial time solutions – this formulation has polynomial time complexity. Several extensions of the model can be considered: (1) addressing complementarity and substitution forms of road projects [3]; (2) incorporating aspects of fairness in the allocation of budgets between to local authorities; (3) addressing the multi-criteria nature of the transportation project portfolio problem [3,8]; and (4) addressing the fuzzy nature of costs, benefits and budgets in the transportation project portfolio problem [3,9]. Moreover, some insights presented in this work can be incorporated in the study of the binary variable optimization formulation, presented in the beginning of this paper.

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GOVERNMENT PERSPECTIVE FOR TWO-ECHELON VEHICLE ROUTING: A MULTI-OBJECTIVE EVOLUTIONARY APPROACH

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Abstract

Urbanization trends bring with them new challenges for city governments. Multi-level distribution is an already-known strategy employed by businesses, and the classic formulation of the Two-Echelon Vehicle Routing Problem (2E-VRP) reflects the perspective of single providers, without regarding the routing decisions of other parties. Various stakeholders (government, businesses, residents) may have conflicting objectives. This work presents a multi-objective formulation of a multi-provider heterogeneous vehicle 2E-VRP, from a city government perspective. To solve the considered problem formulation, a Multi-Objective Evolutionary Algorithm (MOEA) is proposed. An experimental evaluation is presented, demonstrating that the proposed algorithm is capable of finding good quality solutions.

Keywords: *vehicle routing, city government, multi-objective optimization, evolutionary algorithm*

1. INTRODUCTION

Current trends of urbanization and growing economies bring with them rising levels of traffic congestion in cities, especially if the potential development of urban infrastructure is limited, due to costs, popular resistance to large-scale construction projects, or natural accidents such as mountains or rivers (e.g. Asuncion). If the infrastructure cannot be adequately expanded to absorb the rise in traffic, national and city governments must recur to new strategies that optimize vehicle flow to deal with such problems [1].

One possible strategy, already employed by individual businesses and transportation companies, is multi-level distribution of urban goods. This work considers a *Two-Echelon Vehicle Routing Problem* (2E-VRP) in order to design a multi-level distribution strategy from a holistic perspective, useful for city governments. Under certain circumstances there may be reasons to not serve customers directly from a central depot but through intermediate points, generally known as *City Distribution Centers* (CDCs). This can happen for example if there are large trucks that leave the central depot but should not enter a certain zone, such as the inner city, and CDCs are set up outside or on the edges of these restricted areas where the large trucks unload their freight and smaller vehicles deliver the freight to the customers within the areas [2].

In the above described case, it can be said that there are two layers or echelons of vehicles and locations, giving rise to the 2E-VRP [3]. The most studied approach for the 2E-VRP considers multi-level distribution scenarios for products of a single provider [4, 5]. However, each provider in a city solving its own routing problem separately and independently of the others could result in suboptimal solutions for the city as a whole. Furthermore, a city government may have the goal of reducing traffic congestion and pollution, requiring a holistic perspective of *Urban Goods Movement* (UGM) [1,6], considering all providers contributing to city traffic, considering all providers contributing to city traffic.

For this reason, a city government can consider the 2E-VRP as a multi-level distribution scenario with multiple providers and products to regulate this distribution. The described holistic approach that reflects the diverse nature of urban traffic is better adapted to tackle the global problem of urban traffic congestion. In this way, instead of solving several parallel 2E-VRP instances that are not aware of each other, one for each provider or product, a city government can unify these instances by having all (or several) providers share all (or several) CDCs, from where (possibly independent) smaller, greener second-echelon vehicles carry diverse freight to serve the demand of clients in the restricted areas.

When considering the traffic problems in major cities, in the case of the author, it may seem impossible or at least unfeasible to model the whole traffic of the entire urban landscape and apply the aforementioned strategy to the whole city in an attempt to reduce traffic congestion. However, inspired by the classic divide-and-conquer method used so often to solve large problem instances, the goal can be to reduce traffic congestion in just a relatively small area, such as part of the downtown of the city with heavy commercial activity. This area can be a restricted area or the second echelon, while the trips from providers to the CDCs set up on the edges of this area would be the first echelon.

Additional challenges arise when adapting the 2E-VRP to the context of UGM, given the existence and participation of multiple stakeholders, e.g. the city government and businesses. The objectives of the different stakeholders will most likely be distinct and may be in conflict, such as businesses seeking to minimize cost, distance, and time of travel and delivery, and the city government seeking to minimize the number of freight vehicles in simultaneous transit during a given period in the considered area, or the pollution those vehicles produce. A viable solution may require a reasonable trade-off. This situation motivates the consideration of a multi-objective formulation that attempts to simultaneously optimize several objective functions, presenting a Pareto set approximation to the decision makers [7, 12].

The 2E-VRP is a generalization of the VRP which is known to be NP-hard [8] and it is therefore impractical to find the optimal solution in polynomial time. The difficulty is further raised considering the multiple objectives to be optimized, the multi-dimensional nature of the demand in a multi-commodity scenario, the potentially large size of input data given large numbers of depots, customers, and vehicles, and the high cost of routing computation. For this reason, an evolutionary algorithm is proposed in order to solve the problem.

In this work, a novel approach to multi-commodity multi-echelon distribution is presented, considering a mathematical model and problem formulation that considers several providers, heterogeneous vehicle fleets, and multiple objectives previously presented in [9], proposing an initial *Multi-Objective Evolutionary Algorithm* (MOEA) to solve certain instances of said problem. Additionally, an experimental evaluation is presented, demonstrating that the proposed MOEA is capable of finding good quality solutions.

It is important to note that due to space limitations, the authors cannot include more details on the current state-of-the-art on the proposed approaches and a more extended justification. Interested readers can refer to [9] for more details on state-of-the-art and justification on the proposed approach for the studied problem.

2. PROPOSED MULTI-OBJECTIVE EVOLUTIONARY ALGORITHM

Previous work that considers the 2E-VRP with additional characteristics appropriate for a City Logistics context [2] only provides a problem formulation and some standard solution methods. However no algorithm is presented, and to the best of the author's knowledge, such algorithm has not yet been implemented and no computational experiments have been reported.

Evolutionary Algorithms (EA) are population-based algorithms for optimization problems to iteratively *evolve* towards better solutions. *Genetic Algorithms* (GA) are the most common evolutionary algorithms, emulate the process of biological evolution, representing solutions as chromosomes and using mechanisms inspired by evolutionary biology, such as reproduction and mutation. EAs have been found to be especially suited to multi-objective optimization problems [10]. Considering the large amount of input parameters and the multi-objective nature of the formulation considered in this work, an algorithm that guarantees finding optimal solutions would result unfeasible for real-world problem instances. Consequently, a MOEA is proposed and presented next. The proposed algorithm is based on the well-known *Non-dominated Sorting Genetic Algorithm II* (NSGA-II) proposed by Deb et al. [11] which, according to the specialized literature, is currently a reference algorithm even used for comparison with new methods.

The MOEA proposed in this work considers a two-part chromosome designed to represent the assignment of customers and CDCs to vehicles, as well as sub-algorithms considered for optimal vehicle routing on both echelons, that are executed for each modified chromosome on each generation. Specialized crossover and mutation operators that take into account the unique structure of the chromosome were also designed, as well as solution reparation mechanisms.

2.1. Chromosome Representation

In EAs, the representation of any solution is known as chromosome. For the problem considered in this work, a chromosome with two parts has been designed. The first designed part is an array of length m_2 (number of vehicles in second echelon, see notation in [9]) and for simplicity denoted as *Starting Points*.

The second part is a matrix of n_C (number of clients in the second echelon) rows by n_D (number of depots, equal to the number of products as each depot is assigned exactly one product) columns, known henceforth as *Product Delivery*. The *Starting Points* of the chromosome represent the CDCs at which the vehicles in second echelon begin and end their routes. Each cell represents the starting and ending CDC for one second-echelon vehicle and can have any integer value in $[0,n_S]$ (number of CDCS or satellites). A value of 0 indicates that the vehicle is not being used. The *Product Delivery* portion of the chromosome represents which vehicles deliver which products to which customers. Each cell represents the delivery of the demand of a single product to a single customer, and can have any integer value in $[1,m_2]$, unless the demand by said customer for said product is 0, in which case the value of the affected cell will be 0 in all individuals.

An example scenario with 6 vehicles in the second level, 3 depots and products, 3 CDCs, 5 customers, and no demand by customers 2 and 4 for products 1 and 2 respectively, will result in the following corresponding chromosome presented in Equation (1):

$$Starting\ Points = [1\ \ 3\ \ 0\ \ 2\ \ 2\ \ 3] \qquad Product\ Delivery = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 4 & 4 \\ 2 & 5 & 6 \\ 2 & 0 & 4 \\ 6 & 5 & 5 \end{bmatrix} \tag{1}$$

In the solution presented in Equation (1), only 5 of the 6 second-echelon vehicles are used; vehicle 3 is not, as indicated by the value 0 in cell 3 of *Starting Points*. Accordingly, value 3 does not appear in *Product Delivery* as it would be inconsistent with *Starting Points*. Furthermore, the values 0 in (2,1) and (4,2) of *Product Delivery* reflect the lack of demand for products 1 and 2 by customers 2 and 4, respectively.

2.2. Proposed MOEA for M2-2E-VRP

A high-level outline of the NSGA-II-based MOEA for the considered M2-2E-VRP is shown in Algorithm 1. The proposed MOEA receives the following input data:

- Number of depots n_D, number of CDCs or satellites n_S and number of customers n_C (see notation in [9]);
- A first-echelon distance matrix of size $(n_D + n_S)^2$, containing the distances between depots and CDCs, represented by $D^1 = \{d_{i,j}\}$;
- A second-echelon distance matrix of size $(n_S + n_C)^2$, containing the distances between CDCs and customers, represented by $D^2 = \{d_{i,j}\}$;
- The demand matrix of size $(n_C \times n_D)$, containing the demand for each product by each customer, represented by $R = r_i^p$;
- The lists of vehicles, of sizes m_1 and m_2, containing each vehicle's represented by L_1 and L_2;
- The size N of the initial population; and
- The maximum number of generations ***maxgen***.

At step 1, a set of ***N*** random candidates $\boldsymbol{P_0}$ is initialized, whose solutions are repaired at step 2 to ensure that $\boldsymbol{P_0}$ contains only feasible solutions. At step 3, a solution for the first-echelon of each individual is found using an optimal approach. Solutions are evaluated at step 4 using a Non-dominated Sorting process, through which non-dominated solutions are obtained, the first set $\boldsymbol{P_{known}}$ (Pareto set approximation) is generated at step 5. After initialization in step 6, evolution begins (iterations between steps 7 and 16). The evolutionary process basically follows the same behaviour, finally returning the set of non-dominated solutions $\boldsymbol{P_{known}}$ in step 17. Due to space limitations, several details of the MOEA are not presented in this work. In EAs, the crossover operator emulates the mating or "crossing over" of two individuals (parents) to form new individuals (children). For this algorithm, a specialized crossover operator that takes into account the unique structure of the chromosome was developed. From two parent individuals, two child individuals are produced. Each child maintains the *Starting Points* of one of the parents while random rows of *Product Delivery* are swapped between them. In most cases, this may result in unfeasible solutions, so a solution repair method is applied after the crossover.

The parents are then replaced in the population by their children. Crossovers are performed with a 50% probability at each generation. The mutation operator emulates the mutations that occur naturally in the process of biological evolution, allowing the exploration of previously unknown and possibly beneficial characteristics for individuals. For this algorithm, a variety of mutation methods were developed (truck swap, CDC swap, delivery switch, customer swap and consolidate service), and then combined into a single mutation operator where some or all are applied in random order to a given individual. The mutation operator is applied on all individuals in the copied population at each generation. In most cases, this may result in unfeasible solutions, so a solution repair method is applied after mutation.

```
     Input Data:n_D,n_S,n_C,D_1,D_2,R,L_1,L_2,N,maxgen
     Output: Pareto set approximation P_known
1.     initialize set of solutions P_0 of size N
2.     repair solutions in P_0
3.     optimally solve routing in both echelons of all solutions in P_0
4.     evaluate solutions in P_0
5.     P_known = non-dominated sorting of P_0
6.     generations = 0
7.     while generations < maxgen do
8.       Q = copy of P_known
9.       Q' = crossover and mutation of Q
10.      repair solutions in Q'
11.      optimally solve routing in both echelons of all solutions in Q'
12.      evaluate solutions in Q'
13.      Q'' = Q''UP_known
14.      Q''' = non-dominated sorting of Q''
15.      P_known = selection of first N solutions from Q'''
16.      increment generations
17.    return Pareto set approximation P_known
```

Figure 1 – Proposed MOEA for M2-2E-VRP presented in [9]

A number of constraints for any solution to the M2-2E-VRP were presented in [9]. This implies that random generations, crossover, and mutation of individuals may lead to unfeasible solutions. Therefore, a solution repair method was developed, which is invoked at every generation of the algorithm. By design of the chromosome, problems such as multiple vehicles delivering the same product to the same client will not come up. The repair method verifies the customer and capacity limit of each vehicle and corrects if any vehicle exceeds them. It also verifies that vehicles that serve clients have a starting satellite and that no non-used vehicle has a non-zero starting point. The routing of vehicles is performed after solutions are repaired.

3. EXPERIMENTAL RESULTS

To validate the evolutionary approach presented in Section 2 for the M2-2E-VRP model proposed in [9], the following experiment was performed. This experiment concerned the quality of the solutions provided by the proposed MOEA against optimal solutions obtained by an *Exhaustive Search Algorithm* (ESA).

The NSGA-II-based algorithm presented in the previous section was implemented in Python and is publicly available online[1]. The chromosome, crossover and mutation operators, solution repair, and evaluation methods were written and implemented by the authors, while for the NSGA-II framework, including the non-dominated sorting of the populations and procurement of the Pareto set approximation, the DEAP[2] implementation was used. The considered experiment was performed on a Gateway NV55S03u laptop, with following characteristics: AMD A4-3300M Dual-Core Processor @ 1.9 GHz with 4 GB DDR3 RAM (512 MB reserved for hardware, 3.5 GB available) running Windows 7 Home Premium 64 bits OS. The version of Python used was 2.7.9. A tiny problem instance was considered, with characteristics described in Table 1.

Table 1 – Vehicle types used in experiment instances

Vehicle Type	Echelon	Capacity (kg)	Cost (Guaranies/km)	Emissions (gCO_2/km)
Fuso Canter 7C15	1	5500	673.53	408
Renault Master SWB	2	1600	443.82	204
Renault Master LWB		1400	415.37	189
Renault Kangoo		800	400	180
Fiat Fiorino Van		700	392.61	161

The instance is also publicly available[1]. The depots, CDCs, customers, and vehicle types are identified with real-world names; however these are only of use to the observer and are not used by the algorithm, which only returns the numerical identifiers in its solutions. The provider depots, satellites, and customers in the considered instance were taken from a pool of locations in the Greater Asuncion Area in Paraguay. The depots correspond to existing factories or warehouses, and the clients to existing supermarkets and local retail shops. Specialized CDC infrastructure does not exist on the satellite locations used, rather potential locations for multi-commodity distribution centers were chosen. The accurate locations and coordinates were obtained with Google Earth[3], and the distance matrices, with distances in kilometers, using the Geographic Distance Matrix Generator[4]. The distances correspond to geometric or Euclidean distances and are symmetric. The vehicle types used, shown in Table 1, correspond to real-world vehicles. However, although the characteristics of these vehicles are not random and intend to portray actual vehicles with relative realism, they were set arbitrarily, based on available data from diverse online sources, and do not necessarily reflect accurately the specifications of their real-world counterparts.

The demand matrix was generated randomly, by allocating demands between 0 and 700 kilograms (the payload capacity of the smallest vehicle) to each customer-product intersection, in such a manner that the total demand for a single product does not exceed the available capacity of the first-echelon vehicle type, and that the combined demand of all products is less than the combined available capacity of second-echelon vehicles, in order to allow solutions with variable quantities of vehicles. The number of vehicles available at each instance was set arbitrarily, increasing according to the number of customers.

1 https://github.com/HaikoEitzen/ea_m2-2e-vrp
2 https://github.com/DEAP/deap
3 https://www.google.com/earth
4 http://biodiversityinformatics.amnh.org/opensource/gdmg

A summary of the characteristics of the considered problem instance can be seen in Table 2, including the number of depots, satellites, and clients considered, the total demand for all products by the clients, the combined capacity of all second-echelon vehicles, and the number of said vehicles available.

Table 2 – Summary of experimental problem instance characteristics

Characteristics	Tiny Problem Instance
Depots ($\boldsymbol{n_D}$)	2
Satellites or CDCs ($\boldsymbol{n_S}$)	3
Clients ($\boldsymbol{n_C}$)	5
Total Demand	4050
Total $\boldsymbol{L_2}$ Capacity	6000
Available $\boldsymbol{L_2}$ Vehicles	6

A comparison of the optimal Pareto front obtained by an ESA and the Pareto set approximation obtained by the proposed MOEA was performed, in order to evaluate the quality of obtained solutions. For this experiment, one run of the ESA was executed in order to obtain the optimal Pareto set for said instance, and subsequently compared with the combined Pareto set approximation of 10 runs of the proposed MOEA on the same instance. The ESA essentially iterates through all possible *Product Delivery* combinations and, if a certain combination is valid, tests all valid *Starting Points* combinations for the *Product Delivery* matrix, each combination being an individual unique solution. The size of the decision space in the considered instance results in 44,079,842,304 possible solutions, of which 184,112,838 are valid and evaluated by the ESA. Due to the decision space size and time consumption by the ESA, this experiment was only performed on a problem instance with small inputs. The runs of the MOEA were performed with a population size of 200 (***N = 200***) over 200 generations (***maxgen = 200***).

After combining all 10 Pareto set approximations produced by the MOEA into a single set of non-dominated solutions, the optimal Pareto front was obtained, and in considerably less time (17 hours versus 17 minutes). In this manner, it is demonstrated that the proposed MOEA can procure good quality solutions as compared to an optimal solution set in reasonable execution time.

4. CONCLUSIONS AND FUTURE WORK

This work presented a *Multi-Objective Evolutionary Algorithm* (MOEA) for solving a multi-objective formulation of a multi-provider heterogeneous vehicle 2E-VRP, from a city government perspective that was previously presented by the authors in [9]. A first experimental evaluation performed demonstrated that the proposed algorithm is capable of finding good quality solutions when comparing to optimal solutions obtained by an *Exhaustive Search Algorithm* (ESA). These promising findings represent a first validation of the proposed approach for governments to improve the distribution of goods in cities.

Future directions include evaluating the proposed MOEA with other problem instances, as well as evaluating the scalability of the proposed algorithm for solving problem instance with large number of depots, CDCs and customers. Given the novelty of the proposed approaches and perspectives, several other formulations, objective functions and resolution techniques should be evaluated towards a real tool for City Logistics.

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DESIGN AND IMPLEMENTATION OF CRACOW HOUSING ESTATES DURING THE TRANSFORMATION PERIODIN IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Abstract

The concept of "green architecture", closely related to sustainable development, design and ecology is not only a reference to the technical issues in construction, but also, in a wider scope about shaping pro-health spatial conditions that would serve present and future generations, with care for human relations with the environment. The challenge of the modern generations is to achieve a balance between natural environment and man-made spaces. This article presents the development of the new housing estate implementing the assumptions of the sustainable design, including green architecture. It will be characterized by large, open green areas, playgrounds, local services and a provision of collective transport.

Keywords: *green architecture, sustainable design, living environment*

1. INTRODUCTION

The concept of green architecture, closely related to the idea of sustainable development, is a very broad issue, which, depending on the context and possibilities, can be interpreted in a variety of ways. It is crucial, first of all in shaping the housing environment – the areas in which we live, rest and spend the majority of our time. Moreover, green architecture should not be understood only as the technological and material application of pro-ecological solutions, but also a pro-health thinking towards creating urban and social spaces, striving for a balance between the natural and cultural environment.

Problems that are currently connected with housing estates clearly indicate the need to take up the issues of green architecture, in relation not only to the housing environment but all social spaces. Modern generations should strive to maintain a balance between the natural environment and cultural areas created by man, so as to maintain healthy values for present and for future generations. The idea of green architecture should aim to provide the inhabitants of cities with a comfortable and healthy life, contact with the natural environment or social spaces as well as simultaneous access to new technologies.

Cracow's estates prove that in the field of technology and the use of construction materials, we constantly strive to improve health-oriented conditions. However, the ecological shaping of space around the buildings remains a problematic issue. Considering the last five decades, Cracow [1] is characterized by three types of multi-family housing, each of which is distinguished by an emphasis on different environmental aspects in the context of architecture.

2. CRACOW HOUSING ESTATES OF THE 1970's

World War II changed the course of the history by 180 degrees. Poland, as one of the most war-torn European countries, struggled with many issues of urban reconstruction, including housing problems. The deepening housing deficit, also related to the migration of people from rural areas to cities, found its solution in governmental multi-family housing programs. A so-called system of a large slab, known already in Western European countries, allowed the rapid construction of large facilities, providing people with many residential areas. The system was based primarily on typing: not only prefabricated elements of building construction were prepared and unified, but also functional systems, solutions for conducting installation networks and many others. The very form of the buildings was based on the assumptions of modernism, which additionally facilitated the investment process – a simple, geometric form, lack of decorative elements, a raw elevation.

In terms of technology, the large-panel building has its advantages and disadvantages. There are discussions about acoustic problems in the buildings, the need for thermo-modernization, replacement of installations, the low flexibility of functional systems, etc. The undeniable advantages include – location in relation to the city and communication with other areas, the potential of unbuilt space, the possibility of arranging space in a flexible way, green surroundings and accessibility to different types of services. Therefore it can be concluded that some of the assumptions of green architecture are recognizable in the 70's settlements. They are manifested very strongly in the urban aspect, which can be observed on the examples of two Cracow estates: Olsza II and Ugorek. These settlements were analyzed as part of a scientific project carried out for the Cracow City Office under the supervision of Prof. Justyna Kobylarczyk.[2] The diagnosis proved that the multi-family housing estates of those times, despite the inconveniences related to the construction technology and the unattractive architecture without individual characteristics, are "comfortable, living and healthy". Comfortable – because they provide access to important services for the residents. Moreover, the housing estates are well connected. They provide convenient connections to other areas of the city, including the city center. The life span of the area [Figure 2] can be seen in the proximity of service centers, workplaces, and activity points that allow residents to conduct various actions inside the estate, also related to their social life. They support life through the proximity of the neighborly interiors, which were considered by the residents as popular.

Figure 1 – Ugorek housing estate in Cracow
(source:https://ugorekiolsza.files.wordpress.com/2014/03/sm_ugorek.jpg)

Figure 2 - Functional analysis of the Olsza II housing estate
(source: Functional-spatial diagnosis of two Cracow estates: Olsza II and Ugorek, wyd. PK, Cracow 2015)

3. CONTEMPORARY HOUSING ESTATES

Improvement of the favorable living conditions is one of the biggest challenges of modern times. The way of life in urban centers changes due to the specificity of work, lifestyle, technological progress and many other factors. Thus it is natural that the trends influencing the shape of the residential areas are also changing.

Although the principles of sustainable development and green architecture are widely known, they are often overlooked in the process of planning new housing investments. On the one hand, the awareness of the residents conscious of their rights and needs increases, on the other hand, the conditions in which we live are far from those we can define as comfortable.

The basic human needs include safety, intimacy and tranquility as well as the proximity of natural elements, such as green spaces. Such opinion is expressed by the majority of inhabitants of the small cities of Podkarpacie – a region of stagnation located in south-eastern Poland. Landscape values and close contact with nature are perceived as a determinant of the quality of the housing environment. Similarly, a sense of security, intimacy and peace were indicated by the inhabitants of the small towns of Podkarpacie as the most important elements of a comfortable housing area, although they seem to be a much more serious issue in medium and large urban centers.

All these arguments rightly indicate that the modern estates should provide such qualities as safety, privacy, sun exposure, openness, space, and the possibility of communing with nature. Meanwhile, it turns out that, considering urban and spatial solutions, housing estates built in the 1970s are definitely more attractive housing complexes than modern ones, which, although characterized by a higher architectural, material and construction standards, do not retain the preferred urban indicators [3]. For instance, it is difficult to talk about privacy in a situation where distances between the buildings do not exceed a dozen or so meters. It also causes insufficient lighting of the building interiors and spaces between them as well as limits the ventilation possibilities.

Green Architecture, which bases its principles on supporting natural resources, also draws attention to climatic conditions, which, as we know now, are of considerable importance for the increase of the comfort of the housing environment. Adjusting architecture as well as spatial solutions to climatic and landscape conditions, including topography, seems to be a necessity. Such solutions reduce the demand for the thermal energy, naturally protect against too high air humidity and improve circulation.

Figure 3 - Ruczaj housing estate – minimal distances between the buildings
(source: https://krowoderska.pl/wp-content/uploads/2017/05/bloki.jpg)

Due to the increasing intensity of the development and the desire to maximize the use of space, green areas are not introduced into housing estates. Instead, half measures in the form of green roofs or walls are applied, meeting certain formal requirements. These assumptions, however, are not able to ensure the full contact with nature, i.e. the creation of green recreational, leisure or utility areas.

The use of this type of half measures is common in Cracow's contemporary settlements, which are the domain of private investors, whose thinking about sustainable design is limited to meeting the necessary minimum required to provide a biologically active area. One of the examples of such settlements includes residential areas in the north-western part of Cracow - one of the most developing areas of the last decade. New housing estates arise between two urban streets, parallel to each other, and about 500 m apart. Unfortunately, each subsequent fragment is a duplicative scheme of previous compositions, which consists of multi-family buildings, access road and parking spaces. The estates are deprived of any public zones, there are no green or recreational areas. The survey carried out among the residents of the housing estates clearly showed that despite the positive aspects of the location of the housing estates, such as security or low building development, the most desirable feature is the contact with nature. (Bielecka 2015) In addition to the relatively new shopping center created nearby, there are no commercial, medical, or gastronomic centers in the neighborhood. The same applies to green areas, playgrounds for children or areas for sports. The aspect of living and comfortable housing is not assured. Distances to public transport stops exceed one kilometer. Although the estate provides the proximity to services, the vitality and comfort are limited in this case due to the location of the assumption, difficult to connect with other districts of the city. It should be emphasized that the estate is characterized by too high intensity of the development, which makes it impossible to organize recreational and neighboring spaces. Distances between the buildings limit the intimacy of the residents, interior lighting and ventilation. It is difficult to live in such environment. The lack of legibility of spatial solutions is also inconvenient. Being inside the estate, one has an impression of presence in an isolated city, where pedestrian traffic connects with the car, often in a conflicting manner, space is disordered, and there is a shortage of green areas, which in case of such a high intensity of buildings is a necessity. Unfortunately, new housing complexes are often designed in this unfavorable way. It takes place due to the desire to maximize the use of areas free of buildings, which bring profits to the investor. Housing prices are not high, which is why they are sold quite quickly and, as a result, inhabited.

4. ESTATES OF THE "FUTURE"

After a very long period of ill-conceived architectural -urban policy, construction of chaotic and incoherent housing estates, investors are slowly beginning to plan spaces according to the principles of sustainable development, thinking about pro-health shaping of urban areas. The final form of a housing estate is influenced by many factors, mainly economic and financial ones, but several examples distinctively show that the way of thinking of the developers and people interested in buying flats starts to change.

The case study of "*Mieszkaj w Mieście*" *("Live in the city")* housing estate in the west – north part of Cracow represents an example of a large housing estate, a new part of the constantly developing city, which will eventually cover the area of 20 ha, that is over 2,000 apartments, nearly 3,000 parking spaces and 5,000 new workplaces. The investment is to consist of 12 stages (as of today only the first one has been completed and another is under construction), which will include not only residential buildings but also office buildings, multi-level car parks, service and commercial premises, medical points as well as public spaces and green areas.

The main assumption is to create a self-sufficient housing estate, a new district of Cracow, providing the residents with a high standard of living. The first, already completed stage, consist of three multi-family buildings, several meters apart, separated by the "internal" courtyards. Each of them has a slightly different character, therefore the whole assumption is more attractive. The courtyards are arranged in such a way that each of the residents of the housing estate can use them - there are green areas, benches, playgrounds for children [4].

Figure 4 - Visualization of the next stage of the investment along with social spaces (source: www.mieszkajwmiescie.pl)

The housing estate should represent the needs of the local community and it seems that the *Live in the City* housing estate can become such. The urban layout, the right proportions of the buildings and social spaces, green areas, and recreation places mean that the residents will have the opportunity to interact with nature, spend time actively in the open air, and additionally, the housing estate will be properly lined and ventilated. Service and commercial centers are also planned in the nearest neighborhood so that the estate will become a "living" housing estate, while easy accessibility for disabled people and people of all ages will make it a "comfortable" housing estate. It is these features that together create the concept of "green architecture", so closely related to the design. The *Live in the City* housing estate based on the most important idea of sustainable design may become a model for today's housing complexes.

5. **CONCLUSIONS**

Housing estates have significantly evolved over the last 50 years. From the time of large slab blocks, through single-family housing estates, twin buildings to contemporary residential areas, an approach to the design of social spaces has developed. The 1970s, despite many of their social and political flaws, give an excellent pattern of the urban aspect of green architecture. The conscious location of residential buildings at appropriate distances, perfectly matched proportions of the buildings in relation to social spaces, the natural system of insolation and ventilation of settlements are just some of the examples of the correct application of elements of sustainable design. These features are sometimes overlooked in the designs of modern estates – which in turn present a high technological standard, frequent use of ecological materials, pro-health architectural solutions – forgetting, however, that not only the technological aspect represents the idea in question. The latest, projects emerging in Cracow give hope for improvement of this disgraceful trend and return to good practices. *Live in the City* is one of the examples of major Cracow projects, but also the smaller ones increasingly implement the ideas of green architecture. It is worth remembering that what is being created in present times is to serve not only modern generations but also the future ones, those that will function, as we suppose, in an even more culturally changed space.

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STANDARDIZATION IMPACT ON THE DESIGN OF LOGISTICALLY EFFICIENT PRODUCTS – PRELIMINARY STUDY

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Abstract

The need for a manufacturing company to operate in the global market in more and more cases makes it necessary to take into account a variety of aspects in product design processes. Product Design for Manufacturing or Product Design for Assembly have been adopted in industrial practice for many years. In business practice the idea of Product Design for Logistics, closely related to product logistic efficiency, has also come into focus. The article presents the results of the study on the standardization impact on the product logistic efficiency which was based on the example of a global furniture manufacturing company.

Keywords: *design, efficiency, logistics, product, standardization*

1. DESIGN FOR LOGISTICS – DESIGN FOR SUPPLY CHAIN

The economics of finished products manufacturing clearly indicates cost and time are key elements of production process. However, it is pointed out, the product design may often prevent the achievement of expected results. To support more effective manufacturing process, the stage of product design should consider the specific features of product production and assembly processes. The estimates from the industry confirm 70% of the manufacturing costs are determined by the product design. and only 20% of the manufacturing costs is related to the production processes operational stage (production process planning, production methods selection), therefore, manufacturing companies are forced to include the subsequent production processes into the product design process.

The concepts of Design for Manufacturing (DfM) or Design for Assembly (DfA) have been widely discussed in the world literature. Chang, Wysk and Wang [1] proposed a group of 10 basic principles which allow the designers to reduce the production costs. They included, amongst others, reducing the total number of parts in the finished product, using modular systems as much as possible, using as many standard components as possible in the finished product, designing multi-functional parts and components and designing multi-use parts and components which can be used in different finished products

Design for Assembly (DfA) concept is largely based on Design for Manufacturing (DfM) approach but it takes a step further. It allows the designers to have an insight into the assembly process's specific features and conditions [2]. DfA method uses a number of instruments which enable to identify the areas which should be considered in the Design for Assembly process. They include the assemblability evaluation method – AEM proposed by Hitachi [3] and extended assemblability evaluation method [4], productivity evaluation system suggested by Fujitsu [5] or widely used Boothroyd–Dewhurst method [6].

The constant search for new solutions in Design for Manufacturing and Design for Assembly encourages to extend the range of factors that need to be considered. Some researchers point out the design process should include not only the logistic aspects but also the entire supply chain (Design for Logistics, Design for Supply Chain). Domin, Wisner, Marks [7] note the first intuitive attempts to design products, in this case packages, aimed to streamline the logistic processes date back to the 1950's, when the conical bottles for soda beverages were replaced by cans still used in production nowadays. The revolutionary in those days soda beverages packaging system increased the logistic processes efficiency which directly reduced the costs. The authors define Design for

Supply Chain as the optimization of the appropriate supply chain potential and product design. In the authors' view, supply chain limitations and supply chain development are the vital aspects that need to be considered in product design processes. Within the framework of the presented concept the authors propose 9 key product design strategies in Design for Supply Chain concept and they include, amongst others, optimizing product integration level (determining the limit of preliminary assembly by the suppliers), applying industry standards (using standard solutions instead of designing new ones), considering the supply principles and supply planning in the design process (standardization and modularity) and minimizing warehousing costs [7].

It is worth noting that both DfM and DfA concepts in some points are consistent with the guidelines for DfL and DfSC concepts. These are aspects connected with standardization and modularity, multifunctional parts or applying industry standards (standardized details). Further in the paper the issue of standardization and its impact on the product logistic efficiency will be discussed in more detail. From the above presented concept one can clearly see the need to further examine the issue of Design for Logistics in relation to the concept of logistically efficient product [8, 9] and an attempt to set it in a broader perspective of the Total Logistics Management concept [10, 11].

2. PRODUCT LOGISTIC EFFICIENCY AND STANDARIZATION

Product logistic efficiency and logistically efficient product are the author's own ideas which were first described in 2011. Since then, the concepts have been carefully studied in order to systematize conceptual framework of the concepts and determine basic conditions for the logistically efficient products to function in the business reality.

Product logistic efficiency is defined as a set of product properties and features which are subject to logistic processes and were purposefully designed to transfer the finished product through all logistic phases (supply, manufacturing, distribution, disposal and returns) and to be highly susceptible to logistic processes (transport, warehousing, packaging, handling orders, stock management) in the entire supply chain. Logistically efficient product is defined as a product which possesses a set of properties and features, inherent or acquired, which were used or designed to support an effective and efficient flow of products in the entire supply chain. Therefore, the flow effectiveness and efficiency need to address the phase character of logistics: supply phase, manufacturing phase, distribution phase, disposal phase and returns, at the same time, taking into consideration functional (process) character of logistic activities – transport, warehousing, packaging, orders handling, stock management. Product logistic efficiency is an element conceptually enriching the Design for Logistics (DfL). Design for Manufacturing or Design for Assembly are in many cases the 1st step in the company's efficiency enhancement, mostly focused on the manufacturing activities. Design for Logistics provides a variety of solutions which refer to all logistic phases, not only manufacturing but also supply, distribution as well as disposal and returns phases.

Product logistic efficiency in many cases depends on the properties and features of the product itself and is a combination of the customer's requirements and the company's organizational and technological capacities. Based on this assumption, every product has its logistic design compliance, which remains a key issue in the product logistic efficiency concept. Product logistic design compliance includes warehousing-transport compliance, packaging compliance and organizational compliance (which refers to stock management and orders handling). The product logistic design compliance appraisal constitutes a crucial element of the concept.

The literature review shows the significance of standardization as the key element which combines the DfM, DfA and DfL concepts. Standardization is beneficial for both the manufacturing company and the end customer in the following areas:

- economic (cost reduction- production repeatability and mass-scale which guarantee relatively low manufacturing cost, lower warehousing costs, easier material needs planning)

- managerial (i.e. stock management improvement – standardized parts, repeatable, less variety, less warehousing space needed)
- market (improved flexibility ratio, quicker response time to market needs, better quality assurance – standardization facilitates higher efficiency of the activities aimed to improve the product, extending the product life cycle, increasing product reliability based on the production scale) and other [12].

There are more standardization benefits and related costs that could be named. The study results presented in the article should confirm the growing standardization significance in search for more effective and efficient logistics.

3. STUDY METHODS AND RESULTS

Product logistic efficiency is a complex notion difficult to examine. The product diversity offered in the market and their Design for Logistics is enormous. The initial part of the study involved reviewing a variety of industrial products which included some aspects of Design for Logistics. The review allowed to select industrial branches and their representatives (purposefully selected global companies) which, in the author's opinion, best realize the DfL or DfSC ideas. The branches included automotive industry (incandescent bulbs, operational components, brake pads, brake shoes, shock absorbers), electronic industry (smartphones), furniture industry (global furniture retailers) and toy manufacturing industry (building blocks global producer). The selection was based not only on the given product review with respect to the DfL and DfSC concept implementation but also on the product information accessibility in the form of electronic product specifications or user manuals available online. Then the author decided to use case study approach for every assortment item in specific branches to examine various relationships between the concepts of designed products and the DfL (DfSC) guidelines.

The results presented in the article are based on the global manufacturer operating in the furniture industry which adopts the Design for Manufacturing and Design for Assembly approaches and includes the elements of logistics (in the 2009 Polish version catalogue we can read the company's motto – together we strive to maintain low prices, we place large orders in the factories that can provide high quality products in low prices. Then, in order to reduce transport and warehousing costs, we pack our products in flat packs. Now it is your turn – you take home your selected items and assemble them yourself. You buy in low price, we sell more). The company was chosen deliberately and the article presents only partial study results concerning the standardization issue. The study was regarded as a pilot study and two research questions were formulated. The first question was to identify changes in the finished product which were a result of the product logistic efficiency improvement. The second research question was to identify the standardization level of parts used for assembly in the random sample. The investigation was focused on the search for products which were displayed in the company catalogues continuously between the years 2012 and 2017 and had signs of logistic product improvement (product offered in a smaller or more customer-friendly packaging, without the need to compile the product in the internal warehouse, with no customer service involvement, easier for transport, etc.). Next, in order to compare the range of changes in the specific model, electronic and paper manuals were examined. In the second phase random furniture items were selected from the 2017 catalogue, and then, based on the manual available, it was examined which assembly parts are part of the item and their repeatability in other furniture items of different types.

For the first section, a three-seater sofa with replaceable cover and a chair were investigated. The user manuals we managed to acquire were: in case of the sofa the manuals of 2001 and 2017, in case of the chair the manuals of 2000, 2003, 20013 and 2017.

Table 1 – Observed changes in sofa construction

	No of assembly parts	Changes in customer service	Changes in packaging	Price
2001	2 (lock pin – item code 108116; sofa stands – no code)	Item to be collected from the internal warehouse after the payment	Item assembled consisting of 3 modules – home assembly easy, foil packaging	2008 2499.00 PLN (the cheapest version)
2017 (2013)	7 (including the same lock pin – item code 108116; sofa stands – item code 212303 and other elements	Item to be collected from the store warehouse	Item partly assembled – home assembly rather easy, cardboard packaging, some elements vacuum packed	2017 1999 PLN (the cheapest version)

It is worth noting both items hardly changed. Sofa was modified to eliminate the internal warehouse preparation and its construction changed in order to pack it in customer-friendly packaging, easy to be collected from the warehouse by the customer alone. Even though the number of assembly parts increased, the assembly instructions are relatively simple.

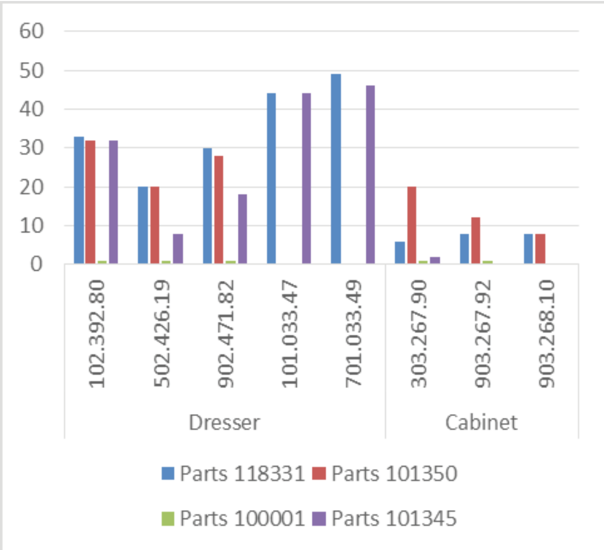
When analysing the corner sofas, it was noted pin lock – item code 108116 was used in all products with the same assembly system.

Table 2 – Observed changes in chair construction

	No of parts	Changes in customer service	Changes in packaging	Price
2000	2 (screw and washer)	Item to be collected from the store warehouse	Item packed in a flat box – easy home assembly, cardboard packaging	No data
2003	5 + hex key (screw different from the previous model)	Item to be collected from the store warehouse	Item packed in a flat box – easy home assembly, cardboard packaging	2008 229.95 PLN
2017 (2013)	4 + hex key (completely new assembly system)	Item to be collected from the store warehouse	Item packed in a flat box – easy home assembly, cardboard packaging	2017 199.00 PLN

To summarize shortly the tables above, it is clearly seen changes in sofas are aimed to facilitate at least 3 logistic processes: transport (smaller packs due to vacuum packing of cushions and sofa dismantlement), warehousing (connected with transport – smaller packs), orders handling (no need to get the central warehouse involved, self-service warehouse). In case of the chair there were no changes introduced to facilitate logistic processes (packages sizes generally remained the same), however, the price decreased by 10%, which id definitely appreciated by the customers.

The next research question was to investigate to what extent the parts in the random sample are standardized. For that purpose, 8 kinds of furniture were selected and they represented 52 variations in total. Each furniture variation was marked with a separate company code. Similarly, each part variation was also tagged with a separate code number. The codes were then entered in the spreadsheet and part of the graph is presented in Figure 3.



	Furniture	Parts Code 118331	101350	100001	101345
Dresser	102.392.80	33	32	1	32
	502.426.19	20	20	1	8
	902.471.82	30	28	1	18
	101.033.47	44	0	0	44
	701.033.49	49	0	0	46
Cabinet	303.267.90	6	20	1	2
	903.267.92	8	12	1	
	903.267.87	14	12	1	10

Figure 1 – A list of parts used in specific furniture variations

Study results show that out of 252 of the investigated parts, only one part - item code 118331 is used in over 50% of the furniture items. Over 13% of the parts is used in over 10% of the furniture items. This variety results from the random sample selection. Table 3 shows that approximately 20% of all parts is used in furniture categories of dressers, cabinets and tables. Within the groups there are parts which appear in all investigated pieces of furniture in the given group, however, they constitute a very low percentage – from 1% to 7%. In case of dressers and cabinets, the highest repeatability ratio is for the level 25%-49%, and in case of the tables it is below 25%. The study results are even more interesting when you realize one should probably expect a significantly higher repeatability ratio for the tables. It turns out that almost 85% of parts repeats in maximum every fourth piece of furniture.

Table 3 – The list of parts used in specific variations

	Furniture	Parts Code 118331	101350	100001	101345
Dresser	102.392.80	33	32	1	32
	502.426.19	20	20	1	8
	602.392.68	34	29	1	20
	703.113.05	28	24	1	12
	902.471.82	30	28	1	18
	101.033.47	44			44
	503.152.91	40			36
	701.033.49	49			46
	701.786.03	26			26
	801.786.07	32			
	101.786.01	20			20

Cabinet	303.267.90	6	20	1	2
	903.267.92	8	12	1	
	903.267.87	14	12	1	10
	903.268.10	8	8		
	703.267.88	8	37	1	4
	402.019.16	18			8

Quantitative spread of the used parts looks slightly different and it is a direct result of the sample selection process. It shows that the most commonly used part (in over 50% of furniture) constitutes little over 10% of all parts used in the sample. Since the whole study, especially the second part, was aimed to indicate the preliminary furniture standardization level, which was accomplished, the necessity for extended research is evident. There is the need to look for relatively homogenous furniture types and focus on the specific furniture group investigating the whole group. Additionally, only the furniture which underwent radical changes in assembly and packaging, should be considered for the study.

4. CONCLUSIONS

The presented study results demonstrate certain tendencies in the use of standardization for the products logistic efficiency improvement. The results of preliminary studies indicate that Design for Logistics creates products which are not necessarily more expensive, however it may result in increased number of parts and the shift of some tasks to the customer in the purchasing process – self-service and use – assembly. The study also shows that the assembly system is changed to reduce the manufacturing operations number, maintaining the minimum packaging standard – the case of the chair back which was previously delivered assembled and in 2017 it is assembled by the customer.

The other study results show that the standardization level is very high, however, the research concentrated on similar furniture construction types (the spread of specific parts appearance allowed to identify the tendency in furniture type concentration) proved there is still high potential for standardization.

The hypothesis that standardization enhances product logistic efficiency, both from the customer's perspective as they obtain relatively similar product at a competitive (often lower) price and from the company's perspective as the supply chains are easier to manage requires further research. Standardization is not the only element enhancing DfL. The issues of using multifunctional parts, modularity concept and its impact on logistic processes and industry standards as ready-made solutions should also be verified.

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PREPAREDNESS FOR EARTHQUAKE DISASTER: OPTIMAL DEPLOYMENT OF EMERGENCY TREATMENT

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Abstract

The official framework of the earthquake preparation policy in Israel presumes that care for all casualties is the main concern and as so defined the necessity of deploying Emergency Treatment Sites (ETS) as part of disaster logistics. These treatment sites will provide medical first aid during the first 72 hours to moderate and lightly injured casualties. While authorities define only one kind of ETS, equipped and positioned in advance, defined here as static ETS, our optimization model suggests adding new mobile ETS that participate under command of the static ETS. These mobile ETS will be equipped and positioned only after an event occurs.

The model is based on minimizing distance on network hierarchical location problems with "soft" constraints, where a set of destruction locations, including casualties and sets of candidate static and mobile ETS are given. The destruction sites and number of casualties are based on Hazus software prediction for a specific area and damage scenario, while the candidate ETS locations are suggested according to emergency safety instructions. The research scenario assumes that a mobile ETS will be connected only to one destruction site and one static ETS within defined maximal distance. A static ETS can serve several sites.

The model we developed will provide the best recommended locations for both static and mobile ETS, that can handle the maximum casualties at minimum duration under given restrictions. Those planned facilities can help minimize uncertainty of policy makers at disaster logistics during the first hours, saving more lives.

Keywords: *network location, disaster logistic, deployment, earthquake, healthcare preparedness, goal programing*

1. INTRUDUCTION

The official framework of the earthquake preparation policy in Israel presumes that care for all casualties is of main interest and as so defined the necessity of deploying Emergency Treatment Sites (ETS) as part of disaster logistics. These treatment sites will provide medical first aid during the first 72 hours to moderate and light condition casualties.

Modeling the ETS deployment and finding their optimal locations and numbers by minimizing distance, is our main interest. While authorities define only one kind of ETS, equipped and positioned in advance, defined here as static ETS, our optimization model suggests adding new mobile ETS that participate under command of the static ETS. These mobile ETS will be equipped and positioned only after an event occurs.

The model is based on network hierarchical location problem with "soft" constraints, where a set of destruction locations including casualties and sets of candidate static and mobile ETS are given. The destruction sites and number of casualties are based on Hazus[1] software prediction for specific area and damage scenario. For preparedness planning, only one damage scenario is being chosen as the basic reference for prediction

1 Hazus: FEMA's Methodology for estimating potential losses from disasters (FEMA- Federal Emergencies Management Agency).

and deployment of the destruction locations and casualties, while the candidate ETS locations are suggested according to emergency safety instructions. The research scenario assumes that a mobile ETS will be connected only to one destructions site and one static ETS within defined maximal distance. A static ETS can serve several sites.

The model we developed will provide the best recommended locations for both static and mobile ETS, that can handle the maximum casualties at minimum duration under given restrictions. Those planed facilities can help minimizing uncertainty of policy makers at disaster logistics during the first hours, saving more lives.

2. LITERATURE REVIEW

2.1. Earthquake healthcare logistic preparedness

According to previous studies [1] the first 72 hours are the most critical hours after an earthquake disaster. evacuation and rescue of casualties providing medical care is an opportunity of saving life. Considering this, the pre-hospitalization emergency medical system, which provides a life-saving treatment in routine, emergency and natural disasters situations, requires rapid preparedness and response to an earthquake event within the framework of national, local and community organization.

Based on injury scenarios of population casualties and to prevent hospitals burdens, the Israeli Ministry of Health defined an operating plan for emergency medical response after earthquake occurs. The response will be given at Emergency Treatment Sites (ETS) to light and moderate casualties while severe casualties, which arrive at the ETS in spite their condition, will receive emergency life-saving treatment and will be transferred to hospitals as quickly as possible.

The ETS is planned to operate during the first 72 hours (three days) or until the opening of the community health assistance centers which are sometimes in the substantial literature referred to as Casualty Collection Points (CCP) [2]. The location of the ETS is supposed to be fixed and known to the public in an open, central and familiar area, but far from buildings that may collapse and as close as possible to the destruction sites.

According to the Israeli Ministry of Health, circa 120 ETS will be establish throughout the country, with about 250-300 casualties in each of them. Some casualties will arrive on their own while others will need the assistance of acquaintances or neighbors. Because of the unique nature of ETS as a temporary medical facility at emergency response stage after earthquake we would like to examine and recommend an optimization model that will help to determine the location and deployment of ETS as part of preparedness and response to an earthquake scenario.

2.2. Facilities location models and healthcare

Mathematical models for locating facilities are designed to help answer such questions as: How many facilities are required? Where should we place them? What part of the demand will they provide? A wide range of facility location problems were reviewed in literature [3] and examined location of facilities for different purpose such private or public sector (factories and distribution centers or government ministries), routine or emergency purpose (airports or fire stations and the first aid stations) including facilities location for natural disasters response. Location of facilities has a great influence on the quality of our lives , e.g. the location of schools or chemical plants, the location of medical facilities, while routines and emergencies can determine our fate [4].

Location problems are known as NP-Hard problems [5]. The solutions are therefore divided into three types: exact, heuristic, and metaheuristic [6]. Accurate solutions are usually good and possible for simplified problems or small systems and usually in a linear environment, whereas heuristic and metaheuristic methods are more commonly used for finding the optimum in a nonlinear environment. The models usually are examined in deterministic form.

A location set covering problem (LSCP) is one of the basic problems investigated [7] in order to determine the minimal set of facilities to ensure supply (goods or services) to demand locations. The model's solution defines the number of facilities required to cover the demand. A demand point shall be considered covered if there is nearby a facility that can provide the required service. The main disadvantage of this method is the total cost derived from locating unlimited number of facilities. The maximum coverage location problem (MCLP) [8] is designed to address the above specified disadvantage and defines the location of P defined facilities to maximize demand coverage given that each demand point is covered by at least one candidate point, sometimes under constraint of distances between demand and a candidate facility and given capacity.

Other common problems are P-center [6] where the objective function minimizes the maximum distance between locations of demand and locations of candidate facilities, i.e. a min-max problem (the problem does not consider the weight of the demands). In problems based on the P-median, the goal is to place P facilities with minimum distance or time between locations. In some cases, we also wish to determine the demand part that would be served at each chosen location. Those problems considered as location-allocation ones.

An accepted distinguish is done between the continuous location models and the network ones [4]. In the continuous location models the candidate locations and the demand locations can be in any place on a plane, while in the network model they can be only on nodes of the network graph and any movement between them can occur via arcs only. In a network model such as a road network or a supply chain, demand sometimes is limited to arcs and nodes [4], and the constraints define the connections and capacity or budget limitations.

The location of medical facilities was the subject of many studies [6]. The health system is basically a hierarchical system [9] and the location of the medical facilities has a great impact on the patients or casualties. The facilities availability and abilities in routine and emergency situations is influenced by decisions regarding the location of the facilities. Peng & Afshari [3] examined 101 locations studies using different methods and applications. They found out that in most of the models the objective was defined using one or more of the following parameters: coverage, cost, distance, time, efficiency or accessibility. Constraints most frequently referred to resources, demand, efficiency, capacity, distance and cost.

In a review of 150 articles on the location of medical facilities [6], a distinction was made between two types of emergency facilities: permanent facilities and temporary facilities. The First aid stations (the Red Cross, the Red Crescent and Magen David Adom - MDA) are permanent emergency facility, while field hospitals, medicine distribution centers during disaster or Casualty Collection Points [2] are temporary emergency points.. The research on temporary facilities for emergency healthcare is limited and [6] found that only 5% of works consider temporary facilities. It seems that the location of temporary medical facilities is mainly deterministic and hard to handle the uncertainty that is characteristic for them. Uncertainty has been addressed in various studies using various heuristic algorithms such as the Lagrangian Relaxation or Tabu Search using dedicated software ([2], [10]). It was also noticed that hierarchical models that characterize the health system during regular situations, are rarely used at emergency situations.

Researchers [3] note that there is a need in expanding the research in response to mobility and changing requirements of facility locations and coverage of emergency situations. The distinction between static and mobile facilities will enable the provision of an accessible, optimal and quick response to the needs of staff and casualties and will assist decision-makers and policymakers better respond to disaster events.

Considering the gaps that have emerged, we would like to examine an optimal quantitative model for the deployment of hierarchical medical emergency treatment facilities - A model that will let authorities provide an immediate medical response at uncertainty situations after earthquake in Israel.

3. RESEARCH OBJECTIVE

The objective of this study is to examine and model an optimal deployment of Emergency Treatment Site (ETS) as part of disaster preparedness.

We formulate and examine an optimization model for location and deployment of ETS, while examining the implication of combining static and mobile ETS as a part of preparedness and response phase to earthquake events. The model will assist preparing for the event and will serve the local authority level as a decision support tool.

4. THE OPTIMAL LOCATION MODEL FOR ETS

The model presented in this study, aims at allowing operational flexibility in operating the ETS and maximizing the coverage of casualties with fast response under capacity constraints. In addition of deploying only "static ETS" that are positioned in advance, the model offers an alternative concept with new entities called "mobile ETS" that their location determined only after an earthquake event. Those mobile ETSs are the part of the original deployment planning, they will not increase the resources requirement for operating, but they will allow better deployment in the area and better coverage of the event in real time. According to this alternative concept, the static ETS will be equipped and manned at the beginning of an event at known locations, while the mobile ETS, bended to each static ETS, will be deployed only after the static ETS opens. A comparison between given operating concept and the alternative one is shown in the example at Figure 1.

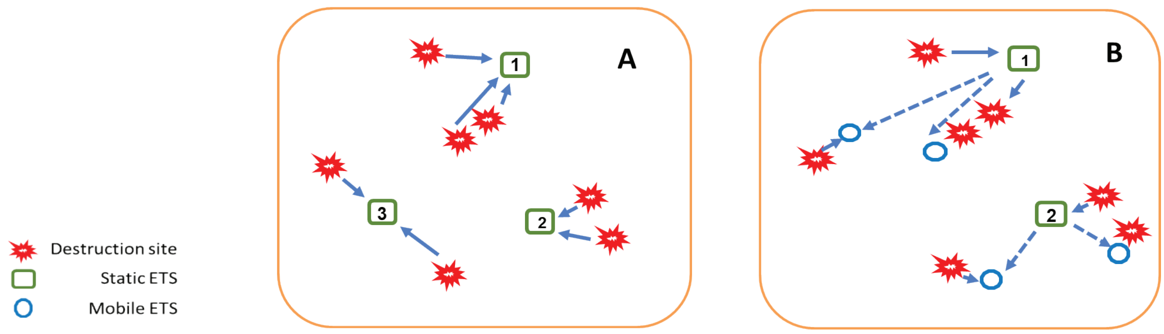

Figure 1 – A- existing operating concept, B- alternative operating concept

At figure 1A we illustrate several destruction locations (7), that are connected to pre-positioned static ETS (3). The arrows are directed from the destruction sites to the ETS as the casualties arrives on their own to the ETS. Figure 1B demonstrate the new concept and shows static ETS (2) positioned before an earthquake happened and new mobile ETSs (4) which are sent and positioned only after the event. The mobile ETSs are positioned near the destruction sites (7). The arrows here are directed both from static ETS to mobile ETS demonstrating movement of mobile ETS teams approaching the destruction sites while on the other direction the casualties arrive to the mobile ETS from destruction sites.

The basic assumption suggested that all resources are provided by a static ETS to its connected mobile ETS. The static ETS locations will be determined in advance and before the occurrence of the earthquake event based on Hazus software forecasts and according to the Israel authority's framework [12]. Each mobile ETS will be activated only by the command from a static ETS and will be connected to only one static ETS. Static ETS can activate several mobile ETS and can take care directly at casualties from several destruction sites . An ETS is limited by its own capacity. Destruction site will be served by one ETS (mobile or static) only - the one that is the nearest to the site.. The distance from a mobile ETS to connected destruction site cannot exceed defined distance. The equipment for the mobile ETS will be packed in bags and doses so that the rescue team can carry it for distance.

Our deterministic model is based on network hierarchical location model [11] where the objective function determined as goal programing based on »soft« constraints. The objective function as formulated at (1), regarding figure 1B, is to minimize the total weighted distances by number of casualties at each positioned

ETS and by that assure the fastest treatment is given. The first part of the equation includes the distances (time approximation) that the mobile ETS teams should pass till they arrive to the mobile ETS locations for the first time. The two following phrases are the total distances that casualties pass from each destruction site to nearest ETS location. The last part of the objective function includes the soft variable and gives us an idea about casualties that did not get treated by ETS at the disaster area. The linear discrete problem is restricted by capacity and distances constraints. The solution will be a recommendation for a set of locations that will define the optimal distribution of the static and mobile ETS for a given scenario. Sets, decision variables, and constraints used in the model are listed below:

Sets:

Candidate locations for mobile ETS, $i = 1\ldots\ldots I$
Candidate locations for static ETS, $j = 1\ldots\ldots J$
Demand locations for destruction sites, $k = 1\ldots\ldots K$

Parameters:

DS_{jk} – the distance between static ETS j and destruction site k
DM_{ik} – the distance between mobile ETS i and destruction site k.
DB_{ji} – the distance between static ETS j and mobile ETS i.
RM – the maximum possible distance between mobile ETS and destruction site k.
PS – the maximum possible number of static ETS
C_k – the number of casualties at destruction site k
MM – the capacity of casualties being treated at mobile ETS per day
ME – the number of mobile ETS members walking from static ETS to mobile ETS.

$$QA_k = \begin{cases} C_k, & C_k \le MM \\ MM, & C_k > MM \end{cases} \qquad \forall k \in K$$

f – he penalty value of not treating the total casualties

Decision variables:

$$x_i = \begin{cases} 1, & if\ \ mobile\ ETS\ is\ located\ at\ candidate\ point\ i \\ 0, & else \end{cases}$$

$$y_j = \begin{cases} 1, & if\ \ static\ ETS\ is\ located\ at\ candidate\ point\ j \\ 0, & else \end{cases} \qquad 0 < j \le J$$

$$z_{ji} = \begin{cases} 1, & if\ mobile\ ETS\ i\ is\ conected\ to\ static\ ETS\ j \\ 0, & else \end{cases} \qquad 0 < i \le I\ , 0 < j \le J$$

$$t_{ki} = \begin{cases} 1, & if\ mobile\ ETS\ i\ is\ conected\ to\ destruction\ site\ \ k \\ 0, & else \end{cases} \qquad 0 < i \le I\ , 0 < k \le K$$

$$s_{kj} = \begin{cases} 1, & if\ static\ \ ETS\ j\ is\ conected\ to\ destruction\ site\ \ k \\ 0, & else \end{cases} \qquad 0 < j \le J\ , 0 < k \le K$$

d_1 the total number of casualties that did not get treated at the ETS for three days.

S- a dummy variable illustrates the total number of casualties that got treated at the ETS on top to the ETS capacity.

$$\min_{z,t,s} \quad \sum_j^J \sum_i^I z_{ji}\, DB_{ji}\, ME + \sum_k^K \sum_i^I t_{ki}\, DM_{ki}\, C_k + \sum_k^K \sum_j^J s_{kj}\, DS_{kj}\, C_k + d_1 f \tag{1}$$

s.t

$$\sum_{j=1}^{J} y_j \le PS \tag{2}$$

$$\sum_{j=1}^{J} y_j + \sum_{i=1}^{I} x_i \le K \tag{3}$$

$$\sum_{i=1}^{I} z_{ji} \ge y_j \qquad \forall j \in J \tag{4}$$

$$z_{ji} \le y_j \qquad \forall i \in i \quad \forall j \in J \tag{4.1}$$

$$\sum_{j=1}^{J} z_{ji} = x_i \qquad \forall i \in i \tag{5}$$

$$\sum_{k=1}^{K} t_{ki} \le 1 \qquad \forall i \in i \tag{6}$$

$$\sum_{k=1}^{K} s_{kj} \le 1 \qquad \forall j \in J \tag{7}$$

$$\sum_{i=1}^{I} t_{ki} + \sum_{j=1}^{J} s_{kj} \le 1 \qquad \forall k \in K \tag{8}$$

$$\sum_{j=1}^{J} z_{ji} = \sum_{k=1}^{K} t_{ki} \qquad \forall i \in i \tag{9}$$

$$DM_{ki} t_{ki} \le RM \qquad \forall k \in K \quad \forall i \in i \tag{10}$$

$$\sum_k^K \sum_i^I t_{ki}\, QA_k + \sum_k^K \sum_j^J s_{kj}\, C_k + d_1 - S = \sum_{k=1}^{K} C_k \tag{11}$$

$$x_i, y_j, z_{ji}, t_{ki}, s_{kj} = \{0,1\} \quad \text{and} \quad d_1, S \ge 0 \qquad \forall j \in J \tag{12}$$

Constraint (2) ensures that the total number of static ETS will be limited by PS parameter. Constraint (3) defines the total number of established ETS as the maximum equivalent to total K destruction sites. Constraints (4) allow each static ETS to be linked to more than one mobile ETS with arcs z_{ji}, while constraints (4.1) demonstrate the hierarchical structure by ensuring that mobile ETS I exist only if static ETS J had established. Constraints (5) assure that only one arc z_{ji} will exit from the mobile ETS to a static ETS. Constraints (6-8) define that destruction site K can receive response from a ETS of one kind only (static or mobile). Constraints (9) assure that each destruction site can be linked to one mobile ETS which connected to one static ETS, by comparing the sum of arcs pointing out from all destruction sites K into a mobile ETS I, to the total sum of arcs pointing out of the mobile ETS to all the static ETS, for each mobile ETS. In order to limit the distances from mobile ETS to a destruction site, we define the maximum possible distance between them as RM (in meters) by constraints (10). Constraint (11) defines the capacity of casualties that can be treated at static or mobile ETS, using "soft" variable d_1 as indication of the number of untreated casualties due to limitation of the potential patient capacity each per static and mobile ETS. Dummy variable S appears also in these constraints and it indicates the number of casualties that exceeded the ETS's total capacity. Variable d_1 is added to the objective function and multiplied by penalty parameter f for failure to meet the full capacity constraint. I.e., the minimum total distance will be augmented because of not meeting the goal of covering the treatment of all casualties in the area (The value of the "penalty" f = 100000, in meters, was determined by us at this example demonstrate large enough distance in the given area). Constraints (12) define the non-negativity and the binary of decision variables.

5. RESULTS

The model, regarding figure 1B, was demonstrated by a small example including 7 destruction sites (K=7), and 3 candidates static ETS locations (J=3) and 5 mobile ETS locations (I=5). The destruction sites were chosen by the author based on approximate age of the buildings per neighborhood at a municipal area, as the center of the area, while the number of casualties was calculated based on population distribution published by the Central Bureau of Statistics of Israel (CBS) based on the National Emergency Management Authority (NEMA) prediction of casualties in the same area. Finely real distances were calculated between all locations (280÷4000 meters). The linear problem included 80 variables and 81 constraints. Assuming only two static ETS locations are required (PS=2), five people (ME=5) as mobile ETS teams and mobile capacity of 50 casualties (MM=50), the model final recommended 4 mobile ETS and 2 static ETS for the given area. Regarding the "soft" variable d_1 and penalty index of f=100000 in the objective function, we found out that not all the casualties would be served and almost 24% of them would be out of the scope. Sensitivity test on the objective function, changing the distance from static ETS to mobile ETS (DSji= 500÷1500 meters), changed the coverage percentage of casualties from 57% to 86% and result in longer distance which represent a longer evacuation time. A model presenting figure 1A without constraints of mobile ETS yielded smaller coverage percentage of casualties with total distance larger than the model above presenting figure 1B.

6. CONCLUSIONS

We found out that adding mobile ETS locations express the efficiency of covering casualties by shortening total evacuation distance. Future research with more detailed cases based on Hazus scenarios and large database, including dozens of destruction sites and candidate locations at a given municipality area, plus sensitivity tests of capacities, distances and number of static versus mobile ETS, will allow us better respond to the emergency event. The contribution of our research focused on optimization model based on network hierarchical location problem as a tool of preparedness for disasters. Suggested combination of mobile ETSs, which be positioned only after earthquake occurs, with static ETSs positioned before the event and the use of "soft" constraints, will help us also to find the optimal locations for better covering casualties and to minimize the total distance and time. At future research with expanded models and a statistical simulation that will demonstrate the arrival distribution of casualties and rescue teams we will try to determine better recommended solution for ETS deployment regarding the stochastic characteristic of earthquake event.

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SUSTAINABLE LOGISTICS AS A DIRECTION OF COUNTERACTING DEVELOPMENT PROBLEMS OF SMALL TOURIST CENTRES

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Abstract

Urban systems are central in logistics. It concerns economy, communication, human resource management and goods. Apart from the negative impact of transport on the environment, it is necessary to apply such tools as legal or environmental regulations, and activities related to so-called "Green" or "sustainable" Logistics. These include the use of standards specifying the permissible emission of pollutants, the use of hybrid engines, the use of ecological consumables such as eco-fuels and others. Particular attention should be paid to the availability, the possibility of providing supply, efficient mass communication, transfer of tourists and unloading of transit traffic. The article aims to highlight the spatial and social consequences of improperly pursued logistics policy, the need to update infrastructure solutions connected with investment plans and to stress the importance of striving to preserve or improve the quality of life in the city as the main objective of its functioning.

Keywords: *sustainable logistics, green logistics, small city, tourist centre, transportation*

1. INTRODUCTION

Szczyrk is a city in southern Poland, in the Silesian Voivodeship, in the Bielski district. The city has a tourist and holiday character. According to the 2017 statistical year (data from 31 December 2016), the city had 5734 inhabitants. [1] Szczyrk lies to the south of Bielsko-Biała, northeast of the Vistula and northwest of Żywiec, in the valley of the river Żylica, in the Silesian Beskid.The city is situated at an altitude between 470 and 1257 m above sea level.

The city plan is dictated to a large extent by the topographical layout of the area in which it is located. Along, indented valley, open only to the east towards the Żywiecka Basin, determines the directional location of the city structure. Urban systems in the logistics dimension are concentrating areas. It concerns economy, communication, human resource management and goods. The growing urban areas and the intensification of their development mean that the processes of planning, implementing and controlling the efficient and economically effective flow of raw materials, materials and products are of particular importance. All the more, minimising the negative effects of activities related to logistics should be treated as a priority action. In Szczyrk, the logistics and communication problems are inseparably connected with the city's tourist and leisure character. Szczyrk is a very attractive tourist city, which is determined by its location surrounded by mountains, an extensive network of routes and ski lifts, and a large hotel and gastronomy base. The periodic influx of tourists, however, generates many difficulties that the city must solve in the shortest possible time in order to apply for the title of the winter capital of Poland.

2. ANALYSIS OF THE MAIN ISSUES

The dominance of individual communication is nowadays the main problem related to transportation, severe in the consequences, especially during the winter. Together with the unusual arrangement of the city, built along the bottom of the valley and the provincial road, it results in difficulties in everyday traffic – traffic jams at fixed times of the day. Columns of standing cars, apart from the problem of quality of solid fuels used in heating systems of single-and multi-family houses, contribute to increased air pollution. Again, the location of the city and the topography of the area plays a major role in this negative phenomenon – the location in the long valley between the slopes surrounding Szczyrk hinders the air exchange. The poor airing of the city is conducive to the phenomenon of residual smog.

Another derivative of the city's communication problems is the number of cars parked in its centrum. Scattered hotels and guest houses with an insufficient number of parking spaces, together with the willingness of visitors to use free parking places along the main road results in excess of cars parked in the centre and thus a restriction of space intended for pedestrians. Assuming the rapid development of Szczyrk mainly related to the recently completed investments in the development of tourist infrastructure under the name "Szczyrk Mountain Resort", decisions about urban development, including the aspect of transport and logistics, should be made at this moment.

In the light of the investments made, Szczyrk becomes very attractive for tourists from the Silesian and Lesser Poland agglomerations, and even for users from the Czech Republic and Slovakia. Therefore increased car traffic should be expected in relation to the situation of previous years as well as the exacerbation of the problems discussed above.

The extended centre has put into operation a large car park for approximately 700 cars located at the main lift (a year-round gondola lift). Car parks near the remaining lifts are mostly private parking lots. These solutions are, however, partial and selectively meet the needs of the city.

3. TRAFFIC MANAGEMENT STRATEGY

Preventing these problems should include the development of a comprehensive strategy for traffic management, in particular for minimising individual communication for collective transport.

To establish this strategy, certain goals should be adopted:

- establishing zones of diverse communication solutions
- identification of the main user groups and prioritisation in particular zones
- defining the principles of organisation and traffic management solutions as well as principles of public spaces organisation in street corridors in particular zones
- defining the impact of these principles on the functioning of the city's transport system and the directions of its development
- an indication of the road investments necessary for improving the system

As far as the air pollution is concerned, pro-ecological solutions should be used, i.e. strive to reduce greenhouse gas emissions, reduction of the energy consumption and the amount of waste generated.

In order to limit the negative impact of transport on the environment, it is necessary to apply, apart from the typical instruments, such as legal or environmental regulations, activities related to the so-called "Green" or "sustainable" logistics. They include among others the use of standards specifying the permissible emission of pollutants, the use of hybrid engines, as well as the use of ecological consumables like eco-fuels and others.

Thanks to the implementation of intelligent transport management systems, it is possible to associate customers with each other, organise group deliveries on one route and use solutions related to the shared cargo area. It is possible within one industry or even within several different industries. It is worth referring to Green (or sustainable) supply chain management (GSCM), which can be defined as the "alignment and integration of environmental management within supply chain management". [2]

It is based on the recognition that "an individual firm's environmental impact extends well beyond its corporate boundaries. The origins of GSCM can be traced back to two functional areas in which companies' environmental responsibilities interfaced with external agencies: green purchasing/supply and reverse logistics". [3]

These types of activities significantly reduce the overall mileages associated with deliveries, and thus meaningfully reduce the levels of exhaust gases. An additional consequence of this approach, apart from the economic effects, is to limit the physical number of transport/supply cars in the area of the city. Striving to limit the impact on the natural environment usually means investments in various fields such as the new means of transport, the development of existing ones, increased level of organisational efficiency or training of drivers in the field of so-called eco-driving.

Such interdisciplinary activities inscribed in the overall concept of the city logistics management should also be reflected in urban development. Parking buffers, also known as "park and ride", located at the main entries into the city can be of particular importance. Such car parks also restrict the entry of cars, mainly passenger cars, into the centre. Therefore, the problem of shortage of parking spaces in inner-city areas is solved, both at free places designated in the main street, as well as in private car parks outside the areas of designated parking spaces.

Such car parks will bring the desired effect only in connection with the introduction of efficient collective transport connecting destinations with car parks. For Szczyrk, the main group of users generating an increased individual vehicular traffic are tourists using the ski infrastructure. Apart from the classically understood public transport, the priority should be to create a public transport line allowing easy access to the start-up locations of the ski lifts. Such system of buffer parking lots supplemented with properly coordinated public transport will relieve the communication system of Szczyrk on many levels.

Logistics flexibility should still be better understood regarding its economic impact and its effect on green logistics. Therefore, "the impact of transport providers' interactions and customer-transport providers' interactions should be established, since it could represent a very significant source of transport uncertainty, and as a consequence have a considerable impact on green logistics performance". [3]

In terms of the mass transport solutions, traditionally considered solutions, such as the introduction of a lane available only for buses, have little use for Szczyrk because the cross-section of the road lane does not allow for its widening: we are dealing with a single-lane of the narrowly-built road. Separate lanes for buses can be introduced partially, which only slightly improves the availability of selected places by public transport in relation to individual transport. It is necessary, however, to prepare bus bays for public transport instead of bus stops.

4. USE OF A COMPACT CITY MODEL

The currently created modern network of ski lifts connecting many slopes of the valley into one system is an important development impulse. It generates a large increase in construction investments in the field of tourism infrastructure, including primary accommodation for individual tourists and small groups. However, it already causes an increase in communication and logistics complications, which in turn decisively changes the conditions determining the quality of life in the city. [4]

In order to preserve the value of Szczyrk as a city of a special character, including concern for the compositional values of the city or their introduction, it would be necessary to look for solutions that refer to the principles of sustainable development. Connecting the implementation of sustainable logistics and sustainable development may result in the achieving a model of the so-called compact city.

The compact city called the city of short distances is an urban concept that promotes a relatively high density of built-up areas together with diverse, mixed use of the land. "An efficient public transport system is aimed to encourage the resignation of car communication, and the compact urban layout is conducive to walking and cycling. [5] A compact city is a model of city development assuming limitation of the building scattering, support for revitalisation and development of degraded areas. [6]

One of the objectives of this model includes the "desire to increase the intensity of the use of urban investment areas and higher intensity of population; intensification of social life as well as cultural and economic activity. The form of the city, its size and structure, is defined in a manner that allows achieving the benefits of sustainable, natural, social and global development as a result of concentrating urban programs". [7] "The compact city model has been recognised in the European Spatial Development Perspective as being in line with the principle of sustainable development". [8]

5. EXAMPLES OF TOOLS FOR IMPLEMENTING A COMPACT CITY MODEL

The Compact City Policies: A Comparative Assessment, presents a summary of the most commonly used tools for the implementation of the compact city model. [9] The tools were divided into five groups due to the type of activities:

► regulatory/informative,
► regulatory,
► fiscal,
► public investment,
► public-private partnership.

The group of tools defined as regulatory and informational includes the creation of all guidelines and plans (created at the national, regional and local levels) regulating the development of urban areas.

Regulatory tools include determining the boundaries of an urban area zone, introducing minimum density requirements or requirements for mixing different methods of the land use.

Activities in the scope of other groups include, for example, various types of fees connected with the transport system aimed at promoting public transport, or various initiatives that encourage investments in areas that have already been used (revitalisation) or initiatives to encourage renovation and conservation of existing buildings.

6. CONCLUSIONS

The tools presented in the article include only a few of the activities undertaken as part of the sustainable development policy and the compact city model. Due to logistic aspects, special attention should be paid, among others, to:

- ensuring communication accessibility
- providing a possibility of convenient supply, understood as a logistic system aimed at supporting the city as a functioning structure and increasing its efficiency, also in terms of the finance
- mass communication as an attractive alternative to individual communication
- transfer of tourists in the winter season: system solutions inscribed in a comprehensive transport policy strategy
- unloading and redirection of transit traffic.

Infrastructure solutions should keep up with the investment plans in the field of tourism or overtake them in order to preserve or improve the quality of life in the city as the primary objective of its functioning. One of the basic tasks of the local self-government is to introduce a development strategy which the main goal is to create opportunities to improve the quality of life of the residents. [10]

Proposals presented in this study constitute an excellent basis for considering the problem of sustainable logistics and its impact on the development of small tourist resorts in the context of assessing the quality of life (as one of the important factors of this development). Taking into account many conditions, for example, related to the health, jobs, the conditions of the place of residence or the possibility of relaxation is necessary.

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SPACE, TIME AND ERGONOMIC ASSESSMENT OF ORDER PICKING USING VERTICAL LIFT MODULES

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Abstract

The efficiency of an order-picking operation both in manufacturing and distribution environments can be enhanced by automated storage/retrieval systems (AS/RS). The main advantage in most AS/RSs is that the operator (picker) stays in one general location and items are brought to the operator by the system, known as "part to picker", "stock to operator" or "end-of-aisle" systems. Such a system is a Vertical Lift Module (VLM), in which an insertion/extraction (I/E) device is traveling vertically and extracts trays or totes from the shelves and brings them to the operator. Potential users are initially attracted to the high density of storage and small footprint of VLMs. However, there are other benefits as well, like increased productivity and better ergonomics, security and inventory control. Despite an increased usage of VLMs, few papers have been written that deal with a quantitative comparison of VLMs with shelving systems as their much more frequently used counterparts. Especially there are no papers dealing with ergonomic assessment of order-picking process with VLM. In this paper, VLMs are presented along with a review of methods for comparing VLMs with shelving systems in terms of space, time and ergonomics. The presented methods can serve managers as tools to additionally justify the VLM implementation.

Keywords: *warehousing, ergonomics in logistics, order-picking, vertical lift module (VLM)*

1. INTRODUCTION

Automated storage and retrieval systems (AS/RS) have been widely used in distribution and manufacturing environments for more than half a century. Various types of AS/RSs exist, capable of storing and retrieving materials (loads) of various sizes and weights. The usage of AS/RSs has several advantages over non-automated systems, like labor costs and floor space savings, increased reliability and accuracy, but also some disadvantages, such as higher investment costs and less flexibility [1]. These advantages are reasons why nowadays various AS/RSs are more often used for order picking. The order picking process is the most laborious and the most costly activity in a typical warehouse. With up to 55% of the warehouse total operating costs [2], it is obvious why many companies are improving their order-picking operations by using more efficient systems. Since traveling amounts to around 50% of the total picking time [2], the logical way of improving this is to reduce or eliminate the unproductive walking time. The efficiency of an order-picking operation both in manufacturing and distribution environment can be enhanced by using an AS/RS. Such a system is a Vertical Lift Module (VLM), in which an insertion/extraction (I/E) device travels vertically and extracts trays or totes from the shelves and brings them to the operator. Although potential users are initially attracted to VLMs because of their high density of storage and small footprint, the benefit of increased productivity is a result of their main advantage, i.e. the operator (picker) stays in one particular location and items are brought to the operator by the system. Hence, these systems are termed "part to picker", "stock to operator" or "end-of-aisle" systems. Additional benefits, often reported by both producers and users, are improved ergonomics, improved picking accuracy (less picking errors), greater security (less theft and damage of stored items) and better inventory control (improved inventory accuracy). Of course, one can expect some correlation between improved ergonomics and productivity. However, although the order-picking process is very laborious with usually ergonomically risky postures of bending, reaching and lifting items manually, research papers about ergonomics (human factors) in order-picking processes are rare and have appeared only recently. Moreover, they focus mainly on manual order-picking systems, i.e. “picker to part” systems where picking is done from static systems like shelving or pallet racks, or walking or traveling between picking locations. Despite the increased usage of AS/RSs, not many papers dealing with a quantitative comparison of VLMs with shelving systems as their much more frequently used counterparts have been written. In particular, there are no papers dealing with ergonomic assessment of an order-picking process using a VLM. In this paper, VLMs are presented, along with a review of methods that could be used to compare VLMs with shelving systems in terms of space, time and ergonomics. Special attention is given to the ergonomic assessment methods that can be applied for quantifying ergonomic benefits. The presented methods can serve managers as tools to additionally justify the implementation of VLMs. The structure of the paper is as follows. In the next section VLMs are described together with a brief literature overview on this topic. The subsequent section focuses on an overview of existing literature regarding ergonomics in order picking. Section 4 presents methods used to compare the VLM with the shelving system based on selected examples, in order to provide quantification of possible differences (improvements achieved when using VLMs).

2. VERTICAL LIFT MODULES

There is a vast number of papers dealing with AS/RSs. However, most of them are related to various crane-in-aisle types of an AS/RS, namely, unit-load AS/RSs, mini-load AS/RSs and person-on-board AS/RSs. The most comprehensive overview of all design and control issues of the AS/RS is given in [1]. Other AS/RS types (horizontal and vertical carousels and VLMs) received much less attention in the literature, whereby VLMs are much less present. Apart from few technical articles (like [3]), the main research paper regarding VLMs is [4], presenting throughput time models for a single VLM or VLMs in pods (a system of several VLMs per one order picker).

VLMs have been in use since early 1970's in warehouse and industrial applications. The first versions were much slower and with a limited capability in storage and retrieval tasks. Modern VLMs provide increased operational speed, greater weight capacities combined with automated control systems and easy-to-use user interface [3]. The main reasons for developing todays sophisticated VLMs are meeting the throughput demand of small parts and layout related constraints [5]. A VLM can be viewed as an enclosed, six-sided box that works using three basic columns, as illustrated on the left-hand side of Figure 1.

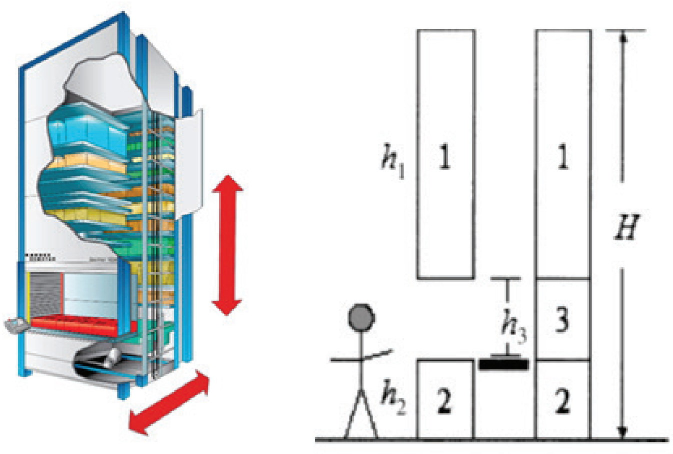

Figure 1 – Vertical Lift Module (VLM) with motion directions of I/E device (left) and schematic side view of VLM (from [4]) (right)

The front and rear columns, functioning as shelves to support trays and totes, are used for storage. The center column accommodates an I/E device, which operates within the front and rear columns in the vertical motion, like a lift or elevator, to store or retrieve trays by order. When a tray is requested by the operator, it is extracted and delivered to the work station window (usually called a pick window). The operator retrieves item(s) and after completion the tray is then returned to its storage location. The process can end after one cycle in a single line order, or it can be repeated depending on the size of the order or a batch of orders.

It can be said that potential users are initially attracted to the VLM because of its small footprint. Space savings, in literature reported to be over 80%, are achieved by taking advantage of the vertical space and high density storage. Costs justification in an order-picking environment becomes much clearer together with other realized benefits. Increased picking productivity could be achieved by faster transaction times because the correct item is always presented for picking (walking and searching through bays are eliminated), while batching and slotting techniques with pre-sorted pick lists could be used to improve the picking productivity even more. However, the elimination of walking time still does not guarantee higher picking productivity due to the relative high waiting time, as will be shown in Section 4. The computerized control combined with optional position indicators and an information display leads to increased picking productivity combined with increased picking accuracy levels. The next important benefit is the VLM's ergonomic solution of the pick window. The VLM almost completely eliminates the need to reach, bend or climb, which reduces potential employee injury related cost, and productivity and accuracy increase (less time to pick items from the most ergonomic position, potential avoidance of productivity loss and increased errors due to the worker's fatigue). The VLM can also be viewed as an enclosed safe storage device that provides effective security of valuable stock-keeping units (SKUs).

Usual VLM systems have only one picking place, so the picker, once he/she performed a pick, has to wait for the storage of the current and the retrieval of the following tray. Recently, some producers of VLMs offer a solution with two pick places, naming it dual-tray VLM (dual delivery configuration VLM, VLM with "double access handling"), which has been presented in papers dealing with throughput time modeling [6] and performance using storage assignments [7]. This version of VLMs is capable of increasing picking productivity even more, reducing or eliminating waiting time of the human picker.

3. ERGONOMICS IN ORDER PICKING

As already mentioned, the order-picking process is the most laborious activity in a typical warehouse. Since most order picking systems used in practice are "picker to part" systems (more than 80% of all orders processed by warehouses are picked manually [8]) with a significant amount of traveling time, the main objective of numerous papers in last decades was to reduce the average distance the picker needs to travel, and thus the order-picking time. The focus was on the determination of the warehouse layout or/and policies, such as routing of manual pickers or batching of orders and assignments of products to storage locations [8]. The human plays a key role in manual "picker to part" systems. Integrating the aspects of ergonomics into the workplace design is not a new topic (there are many papers dealing with ergonomics in manufacturing and assembly environments), recognized also in practice in internal logistics and manual material handling. In manual "picker to part" systems, activities require manual material handling tasks, such as lifting, lowering and carrying loads, while usually associated with awkward postures, such as reaching and bending. Order-picking activities involve repetitive tasks that may result in musculoskeletal disorders (MSDs) for workers. MSDs are the most reported causes for absence from work. They account for over 52% of all work-related illnesses and more than 2% of the gross national product in the European Union, where low back disorders are the most costly of all MSDs [9]. However, scientific literature on ergonomic aspects in order picking is scarce and started to appear only in the last few years. This was recognized in [9], so the authors developed a conceptual framework that identifies steps in an order-picking process where human factor issues are most prevalent, and made suggestions as to how order-picking models could be improved in future research. This research was followed and supported by [10], where the authors did a content analysis of the literature about the human factor in order picking, concluding that the focus of the literature on manual order picking has mainly been on economic aspects, and that human factor issues have not been mentioned very often; only 16 papers study the human factor in order picking. Most of these papers analyze the link between certain control policies in manual order picking systems (storage assignment, batching, and zoning) or aiding technologies (paperless picking, such as vision picking, voice picking, and pick to light).

Although the application of AS/RSs, or particularly VLMs, is aimed to reduce the distance workers need to walk (improved ergonomics regarding reduced walking and carrying items), with additional ergonomic benefit of picking from the most ergonomic position (golden zone), no papers are particularly devoted to this issue. However, approaches and results from research presented in some of these papers might be used to assess ergonomics of picking from VLMs. Especially the papers dealing with storage assignment. The identification of differences between the shelving system (picking from different heights, i.e. levels of shelves, with walking between storage locations) and VLMs (picking from the ideal, golden zone location without walking) could be done by using the methods proposed in the following several papers. Battini et al. [11] developed a bi-objective model that considers both total order-picking time and human energy expenditure. Time and energy expenditure depend on the main features of the order-picking system, such as item characteristics, item popularity, order profiles, and physical dimensions of the shelf and locations. Larco et al. [12] similarly studied the trade-off analysis between the time-based function and the ergonomics-based function, however, unlike in [11], where energy expenditure was used for the ergonomics-based function, here the authors studied worker discomfort using the Borg CR-10 scale, which is commonly used in the field of ergonomics. Otto et al. [13] analyzed storage assignment and zoning in the fast pick area from a case gravity flow rack, in order to minimize the maximum ergonomic load for a given workforce of order pickers (to limit the risk to each single worker). SKUs were given some ergonomic risk factor depending on its weight, pick frequency and position (shelf height). To quantify the ergonomic risk the authors used the NIOSH lifting equation and an approximate ergonomic parameter and showed that simple approximation of complex ergonomics measuring methods leads to a significant reduction in ergonomic risks. In this paper, we used the energy expenditure calculation, presented in the next section.

4. COMPARISON BETWEEN VLM AND SHELVING SYSTEM

To justify VLMs in comparison with shelving systems, apart from only space saving, one should try to quantify the benefits of the decreased picking time along with improved ergonomics.

For illustration purposes, one example was selected, shown in Figure 2. The shelving area with 8 shelves 1.74 meter high (5 levels with 0.348 m height) has a total of 74.12 m^3 storage space. Taking the usual relatively low space utilization of shelves into account (according to [14] the utilization of shelving was established to be 30%), the total required storage space of a VLM was calculated and used to define the VLM's configuration (based on Kardex XP700). The required storage space fits into one 7,050 mm high VLM with 50 trays, 2,700x864x200 mm in size. Comparing the total space required (as illustrated and calculated in Figure 2), the floor space saving is more than 90%.

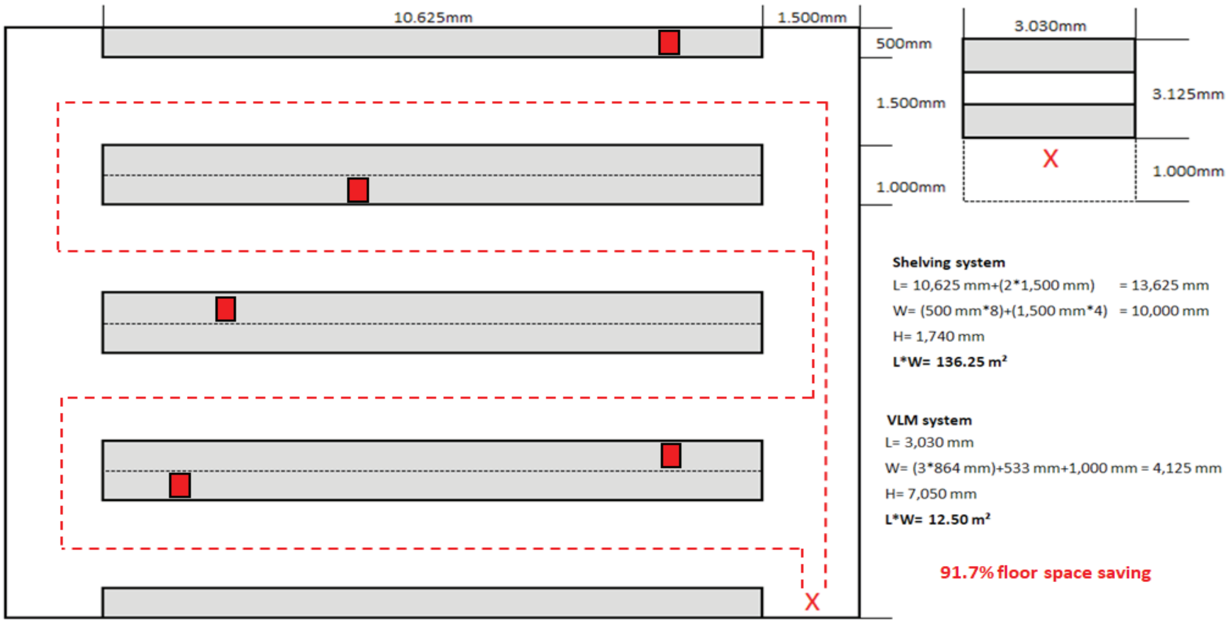

Figure 2 – Space assesment comparison and picking route illustration

To compare the VLM with the shelving system in terms of picking time (picking productivity) an analysis of various picking order sizes (5, 15, 30 and 45 picks per order/batch) was done. As already said, picking in the manual "picker-to-part" system requires walking from one pick location to another, usually with some additional time required for searching and higher pick times due to the bending and reaching of units. When picking from a VLM as "part-to-picker" system, trays are delivered to the picker and picking is always done from the most convenient location. Therefore, pick time per unit is reduced. However, while picking from shelves requires travel, picking from a VLM requires waiting for the next tray to be delivered. In Table 1, results of a comparison are given for selected values of different parameters. For order picking from the shelving area the calculation of the order-picking time is based on the assumed S-shape routing strategy (traversing all aisles in a serpentine way), as illustrated in Figure 2 by the picking route. Travel time was calculated by using the model presented in [15] for the calculation of the travel distance. The time to pick an order from the VLM was calculated with the model presented in [4], based on the expected time to pick items in an order or batch of orders and the expected time to retrieve trays with item(s) from the VLM comprised of sections illustrated on the right-hand side of Figure 1. The latter depends on the expected number of trays to be delivered (more different SKUs are stored in one tray, therefore more picks could be done from the same delivered tray). The results show that for the selected examples the total time to pick an order from the VLM is even longer than in the case of picking from shelves, even the pick time of a unit is shorter. The waiting time for the next tray (which is actually dual command time of the VLM) is considerably longer than the travel time between locations in the shelving system. Of course, this is a case in this selected example with a relatively small shelving area. In larger storages, travel is much more extensive. Replacing such a system with more VLMs in pods (more VLMs per picker) or using dual-tray VLMs could have the opposite effect.

Table 1 – Time assessment comparison

Parameters	Single	S-shape				VLM				
n (number of items to pick per order/batch)	1	5	15	30	45	1	5	15	30	45
H (height of the rack/VLM), m	1.74	1.74	1.74	1.74	1.74	7,05	7,05	7,05	7,05	7,05
h (shelf/tray height), m	0.348	0.348	0.348	0.348	0.348	0.2	0.2	0.2	0.2	0.2
m (number of trays stored in VLM)						50	50	50	50	50
Number of SKUs (Stock-Keeping-Units)	595	595	595	595	595	595	595	595	595	595
p (time to pick one item), s	8.244	8.244	8.244	8.244	8.244	3.126	3.126	3.126	3,126	3,126
v (speed), m/s	1	1	1	1	1	1	1	1	1	1
a (acceleration), m/s²	1	1	1	1	1	1	1	1	1	1
h_1						5.2207	5.2207	5.2207	5.2207	5.2207
h_2 *Height of sections of VLM, m*						0.8333	0.8333	0.8333	0.8333	0.8333
h_3						0.996	0.996	0.996	0.996	0.996
E^V *[R(n,m)]* expected time for travel/retrieval, s	19.13	84.50	94.50	109.50	124.50	35.86	143.28	376.77	649.40	850.75
E^V *[P(n,m)]* expected time for picking, s	8.24	41.22	123.67	247.33	371.00	3.126	15.63	46.89	93.79	140.68
E [S(n,m)] expected number of delivered trays						1	4.80	13.07	22.73	29.86
E^V *[T(n,m)]* expected time for one order/batch, s	27.34	125.72	218.17	356.83	495.50	21.05	158.91	423.66	743.18	991.43

For the ergonomic assessment of the VLM the calculation of energy expenditure was used, based on the equations and values given in [16]. The energy used to pick an order from shelves depends on the energy used for walking and picking from different levels (bending, reaching), while in the case of picking from a VLM this is the energy used for standing and picking from the most ergonomic location. The results are summarized in Table 2.

Table 2 – Energy assessment comparison

Parameters	S-shape				VLM			
n (number of items to pick per order/batch)	5	15	30	45	5	15	30	45
Energy for walking/standing, kcal	10.14	17.59	28.77	39.95	4.19	11.18	19.61	26.16
Energy for picking, kcal	3.97	11.92	23.85	35.77	2.87	8.61	17.22	25.83
Σ Energy per order, kcal	14.11	29.51	52.62	75.72	7.06	19.79	36.83	51.99
E^V *[T(n,m)]* expected time for one order/batch, s	125.72	218.17	356.83	495.50	158.91	423.66	743.18	991.42
Energy per one pick, kcal	2.82	1.97	1.75	1.68	1.41	1.32	1.23	1.16
Possible orders in one hour	28.63	16.05	10.09	2.27	22.65	8.50	4.84	3.63
Possible picked items in one hour	143.17	247.52	302.66	326.94	113.30	127.46	145.32	163.40
Energy per hour performing max orders, kcal	404.07	487.01	530.85	550.15	160.02	168.16	178.42	188.80

According to the obtained results, it is obvious that picking from a VLM is more ergonomic than picking from shelves due to less energy spent for standing than for walking and less energy needed for picking from the so called “golden zone”. In Figure 3 the results for the picking productivity rate and the energy expenditure per picked items are summarized.

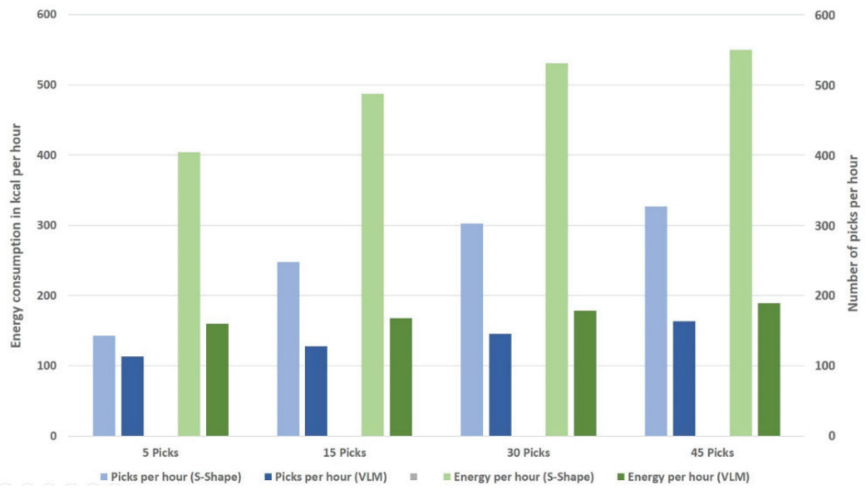

Figure 3 – Comparison between picking productivity and energy expenditure

Apart from the assessment of the used energy, one might also assess the risk. Picking heavier items, especially from the lowest and highest locations of shelves, might pose high risk of injury. Picking from the most ergonomic locations reduces this risk. However, the application of methods for risk assessment, for instance the NIOSH lifting equation, is more complex, requiring inclusion of the frequency of picking (in the case of a shelving system with various heights).

5. CONCLUSIONS

In the presented paper, VLMs, a type of automated storage and retrieval systems, were presented. The focus was on space, time and ergonomic assessment of VLMs in comparison with the traditional manual picking system with shelving racks. With one selected example, it is confirmed that significant floor space savings are achievable. However, the claim that VLMs will also provide time savings due to the eliminated walking is questionable. Although walking is eliminated, there is a waiting time inherited in the process of picking from a VLM, leading in some cases (as it was in the selected example) to longer times to pick an order than in the case of picking from the shelves. Other examples, with larger shelving areas replaced with more VLMs in pod or dual-tray VLMs, might show time savings as well. The ergonomic assessment, done by energy expenditure calculations, proved that VLMs are more ergonomic order-picking systems. This was, of course, expected, but the obtained results might give managers proof and more confidence in such claims. More research is needed to try to calculate (estimate) potential reduction in speed of walking and picking due to the higher energy expenditure and fatigue in shelf picking, which could lead to lower productivity. As an addition to the ergonomic assessment of VLMs, research on assessment of risk of injury should be done in the future.

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SCHEDULING ON-GOING RESEARCH AND DEVELOPMENT PROJECTS

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Abstract

Projects are often described as one-time efforts to achieve a specific goal. However, many typical R&D projects are often not originally planned to end at a specific date or event, but (if successful) continue to the next version release and the one after, for the foreseeable future.

The current scheduling methods developed for project scheduling do not provide the required tool for on-going project managers. A novel application of clustering methods was developed to tackle this problem and provide (near) optimal scheduling and allocation of features to releases, based on precedence, values, resource demands and durations.

Keywords: *combinatorial optimization, scheduling, cluster analysis, release, continuous projects, version release*

1. INTRODUCTION

A project is defined by the PMBoK [1] as "a temporary endeavor undertaken, to create a unique product or service". By this definition every project has a definite beginning and a definite end. Despite this definition, modern research and development project are often planned for many releases and not to a specific single end. Whereas this phenomenon is not new [2], never has it been so widespread and prevalent. There are many examples of this phenomenon [3] and many hi-tech products, such as iPhones, MS-Windows, MS-Office, communication equipment are released to the market at spaced time intervals. The software industry has struggled for a long time with the problem of release content and dates [4].

Version release planning is a complex problem, as appropriate understanding of planning objectives and technical constraints are required for a good release plan [5]. The concept of releases is quite old and emerged firstly with the concept of road mapping back in the 1970's [6], however, road mapping methodology includes mostly qualitative tools and lacks quantitative capability for planning and scheduling [7].

The problem faced by both practitioners and researchers is the allocation of features to releases. As typically, each feature is composed of several activities, and since the activities are often shared by several features, this problem is very complex [8]. A more simplified and myopic version of this problem is the well-known next-release-problem [9], which narrows the problem down to one release and tries to maximize the value [10].

The differences (and similarities) between 'regular' and on-going R&D projects are depicted in Table 1.

Table 1 – On-going vs. 'regular' project

Subject	'Regular' projects	On-going projects
Duration	Finite – There is a prior condition for the project ending	Non-finite. The project may have many releases until there is no market value.
Goal	Project termination	Many goals – one for each release
General nature	Non-repetitive	Non-repetitive
Structure	Inter-connected activities (net)	Inter-connected activities (net)

Critical path or chain	Very important – determines objective	No importance as may change with the change of release dates
Content	Fixed – capacity determines duration	Release dates determine content
Activity importance	All activities have the same importance – needed for project goal	Different activities have different importance, depending on the versions and features
Bottle neck	May be any resource, depending on the importance of the activities Usually the most utilized resource	Depends on the release.

2. PROBLEM DESCRIPTION

The concept of allocating project features (and activities) to releases is an expansion of the scheduling of project activities to achieve maximal net present value. The concept of maximizing NPV from completion of project activities before completion of the whole project was investigated [11] and a thorough survey and classification of the concept of maximization of the net present value can be found in Hartmann and Briskorn [12].

Based on this concept, the following problem can be formulated.

The objective function is:

$$\text{MAX} \quad \sum_{\forall v \in \mathcal{V}} \left[\beta(\tau_v) \cdot \left(\sum_{\forall f \in \mathcal{F}} \mathrm{a}_f \cdot x_{f,v} \right) \right]$$

Where $x_{f,v}$ are the scheduling control factors:

$$x_{f,v} = \begin{cases} 1 & \tau_{v-1} < t_f \leq \tau_v \\ 0 & otherwise \end{cases}$$

Subject to the regular technical precedence constraints:

$$t_j - t_i \geq d_{i,j} \qquad \forall \{i, j\} \in \mathcal{A}$$

Where $\mathcal{A}$ is the set of all activities.
And the classical resource constraints:

$$\sum_{\{i,j\} \in S_t} \rho_{r_{\{i,j\}}} \leq \rho_r \qquad \forall r \qquad t = 1 \ldots t_{max}$$

It is easy to see that this problem is NP hard, by reducing the problem to the knapsack problem for example. Regarding this problem as a mere scheduling optimization problem lacks in several ways:

It is easy to see that this problem is NP hard, by reducing the problem to the knapsack problem for example.

Regarding this problem as a mere scheduling optimization problem lacks in several ways:

- Complexity – even the simple example depicted, creates a rather hard problem to solve. An optimal solution for a medium size problem is by far more complex.
- Partial modeling of the real problem: the mathematical formulation fails to encompass the full details of the problem. Typically, there are no cash flows directly involved (as no one can accurately determine the cash flows derived from a specific feature). However, there is indeed a value for each feature that needs to be assessed.

The problem complexity renders all exact solutions as unpractical for large scale problems. However, using techniques taken from the clustering body of knowledge provide methods that enable the clustering of features to releases.

3. SOLUTION CONCEPT

The body of knowledge developed for clustering purposes, provides a powerful tool to cluster together features that enhance the total value of the releases. These method help generate a feasible solution, as depicted in Figure 1.

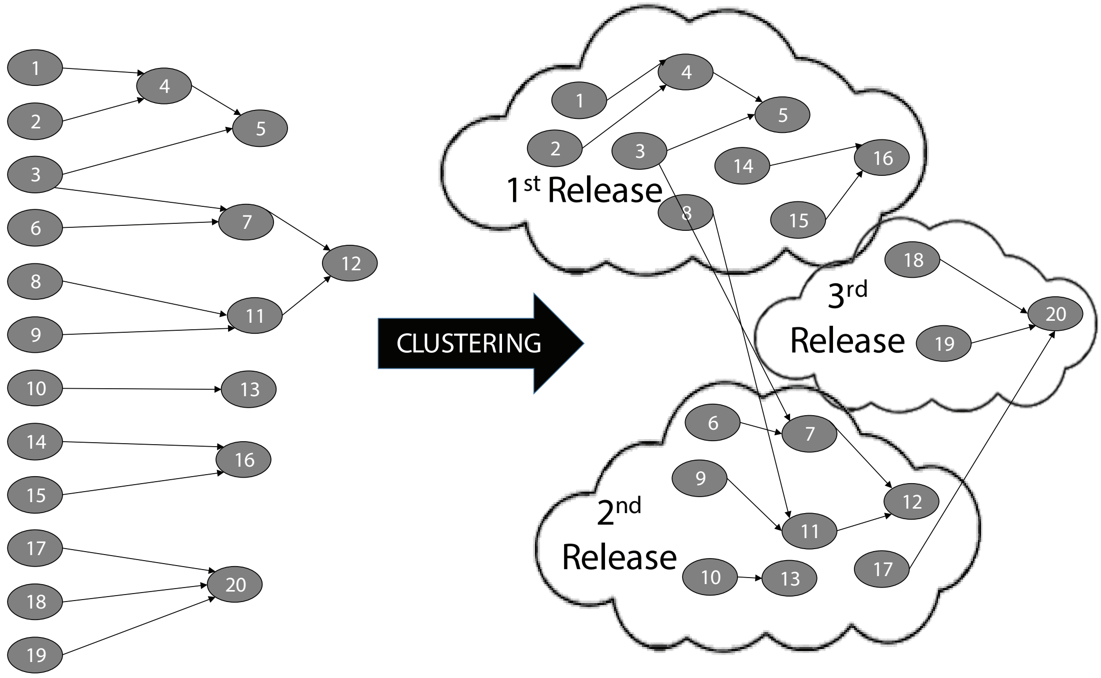

Figure 1 – Clustering process

4. CONCLUSION

The research introduces and analyses a new type of problem that characterizes R&D processes and continuing projects in general. So far solving the problem using clustering techniques was found to give superior results to other approaches. The research is on-going and preliminary results are presented.

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HOW TO ASSESS BALANCING PUBLIC TRANSPORTATION

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Abstract

This paper is devoted to assessing equalization of urban public transport (UPT) timetable with commonly used statistic measures. In order to provide passengers with reliable collective transportation service in networks with long overlapping route segments, attention should be paid to interval synchronization at radial network segments. The purpose of balancing UPT timetables is explained, and evenly-spaced timetables are discussed. Problems with assessing balanced timetables are illustrated with four cases of possible timetables at a congestion node served by two lines of different headways.

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Keywords: *public transportation, interval synchronization, bus timetabling*

1. INTRODUCTION

Generating timetables in urban public transport is the art of compromise, since collective transportation systems have numerous stakeholders with various – often contradictive – objectives, which need to be taken in consideration. Well-designed timetables should not only provide reliable and smooth collective transportation service, but also should minimize passenger waiting time and their total travel time [1–3]. Timetabling is one of decision-making problems faced by planners of urban public transport (UPT), which have to set departure times from the depot of each trip of each line, so that bus arrivals at nodes are organized in particular patterns in order to satisfy passengers transportation needs. There are nodes in the network where passengers interchange from lines running in one direction to lines heading to another part of the city. In such nodes passengers are interested in minimizing interchange waiting time. But another objective is also important in UPT systems with long route segments served by several lines: balancing joint perceived ride frequency at these long overlapping route segments. Passengers appreciate, if in congestion nodes – the first nodes of long overlapping route segments – waiting times for the next trip of any line are equal or almost equal.

Urban agglomerations – when expanding – join peripheral territory to transform them into suburban residential areas, but in return regular suburban and regional collective transport service is offered within an integrated public transport system. In such networks operate radial lines – which can be either cross-city lines or parts of ring-radial systems – and feeder lines. In order to provide passengers with reliable collective transportation service in networks with long overlapping route segments, attention should be paid to interval synchronization at radial network segments. Urban mass transport network operates with a given set of lines and associated ride frequencies (nominal headways) that must be offered. What is more, travel times between subsequent stops in a route were assumed to be pre-defined including the extra dwell time at nodes. Sometimes special emphasis is put on homogeneous headways, but more frequently heterogeneous headways in planning periods were observed. Heterogeneous headways result from corrections introduced to timetables to obtain desirable synchronization or to reduce bus congestion at important transfer stops, which was not possible with homogeneous headways of synchronized lines. In many UPT systems passengers are not provided with information on exact time of bus arrival at each stop, they only know estimate waiting time between consecutive trips of each line, therefore departure times of all trips of all lines should be almost evenly spaced [4–10].

This paper is devoted to assessing equalization of UPT timetable with commonly used statistic measures. In Section 2 the purpose of balancing UPT is explained, while in Section 3 evenly-spaced timetables are discussed. In Subsection 3.2 problems with assessing balanced timetables are illustrated with four cases of possible timetables at a congestion node served by two lines of different headways. Conclusions are presented in Section 4.

2. THE PURPOSE OF BALANCING PUBLIC TRANSPORT – TRANSFER SYNCHRONIZATION VS. INTERVAL SYNCHRONIZATION

Radial lines which link a city center with residential areas frequently have overlapping long route segments. A long overlapping route segment consists of ca. 10 intermediate stops and the order of arrivals of all trips of all lines and separation times between subsequent arrivals at the first stop (congestion node) is repeated at every stop belonging to the segment. There is a group of passengers that travel along such route segments and they are substantially interested in having evenly spaced timetables at stops they get on and get off every day. The unique feature of passengers traveling along long overlapping route segments is that they do not pay attention to what line they take, because all of the lines serving this route segment provide these passengers with direct origin-destination travel service. These passengers mainly pay attention to so-called joint ride frequency they perceive at stops belonging to a long overlapping route segment. Critical for such route segments is to obtain interval synchronization of lines at the congestion node, so that arrival times of any two trips can be evenly distributed. It is obvious that such a situation is possible only for a set of lines of the same headways.

Due to the fact that for a single line separation time between arrivals of its two subsequent trips should equal the nominal headway, the objective of interval synchronization is: intervals between subsequent arrivals of trips of different lines at the synchronization node should be evenly spaced in time. In other words, there should be an interval between two subsequent arrivals that repeats itself for as many pairs of subsequent trips as possible for a given set of synchronized lines. Interval synchronization becomes more complicated when a congestion node is served by a set of lines of different headways.

The specific character and objectives of interval synchronization is clearly visible when we compare interval synchronization with transfer synchronization. The specific goal of transfer synchronization is to reduce waiting time between arrivals of different lines to the desired value. The more pairs of arrivals have separation time that falls within the range of values (time window) indicated by a scheduler, the better synchronization in that node is. What is more, in a given planning period prevailing transfer direction between lines in a transfer node may be observed, which means that a passenger flow changing from line *A* to line *B* is much greater than the one heading to the opposite direction (from *B* to *A*). In such a situation schedulers strive to adjust separation time between arrivals of *A* and *B* to fall within the defined range and waiting times between *B* and *A* are less important and may be shorter or longer than the limits of the time window. Obviously, when separation times between subsequent arrivals of different lines computed with a method designed for transfer synchronization are greater than zero, bus bunching in a given transfer node is also avoided. Therefore, in numerous scientific works devoted to UPT synchronization problem the authors state that their methods synchronize arrivals at transfer nodes and prevent buses from bunching [11–13].

It should be emphasized here that these methods do not guarantee that arrivals at synchronization nodes are evenly spaced in time. On the contrary, interval synchronization is the congestion avoidance synchronization, so the main objective here is obtaining evenly-spaced intervals between arrivals of lines *A* and *B* as well as between arrivals of lines *B* and *A*. Interval synchronization problem is mentioned in numerous works on transit network timetabling, but to the author's best knowledge works on the congestion avoidance synchronization problem in urban public transportation is relatively scarce [5, 12, 14–16].

3. AN EVENLY-SPACED TIMETABLE

As it was already mentioned, the objective of interval synchronization is to provide a congestion node with a timetable with equalized intervals between subsequent arrivals of trips of different lines. Due to the fact that equalization of separation times between arrivals of two subsequent trips of any lines depends on line headways, in this paper the focus is put on balancing intervals between consecutive trips of different lines. Equalization of a timetable was assessed using performance measures commonly applied to UPT timetables. A brief summary of objectives utilized in models for UPT synchronization problem is presented in [7, 16].

Two main approaches to measuring timetabling synchronization are observed: the first is based on the number of synchronization events, and the second refers to waiting time (average or total). The total (interchange) waiting time is the most common performance measure, and the objective is to minimize it. Interchange waiting time is understood as a separation time between arrivals of trips of different lines; in some research the authors define transfers as changes from line *A* to line *B* and minimize waiting time with respect to this assumption [e.g. 17]. In other works, waiting time refers to transfer from line *A* to *B* as well as to changes from *B* to *A* no matter if one immediately follows another or they are separated by arrival of any other line [e.g. 18]. As far as maximization of the total number of synchronization is concerned, it also does not matter if line *A* arrives immediately after line *B* or they are separated by an arrival of any other line [e.g. 14, 19]. In the majority of works the measurements became objectives implemented in optimization models. Moreover, most frequently one measure (e.g. the total waiting time) – and consequently one objective – was enough to achieve desirable transfer synchronization of timetables, what is not possible for interval synchronization. As the objective of interval synchronization is to balance intervals between consecutive trips of different lines, the interval is understood as an interval between the arrival of a trip of line *A* and the arrival of a trip of line *B* and no other trip arrives in the meantime [16].

In [16] the coefficient of variation (*CV*) of intervals between consecutive trips of different lines – which is a measure of dispersion defined as the ratio of the standard deviation to the mean [20] – is used as the performance measure of timetabling equalization at a synchronization node. The less the value of *CV* is, the greater equalization separation times is obtained. Using *CV* of intervals as a performance measure, we get information on dispersion of intervals between consecutive arrivals of different lines at a given node, so we can compare timetables and choose the one where arrival times at given nodes are as evenly spaced as possible.

3.1. Measures

The objective is to minimize dispersion of intervals between subsequent arrivals of different lines, so the main performance measure of timetable equalization is CV of intervals. However, when we have to deal with a bund of lines with different headways, it is better to include also possible performance measure as well, because they can demonstrate other aspects of the timetable under examination.

The problem with assessing the balance of UTP timetable is illustrated with the following example: there are 2 lines with fixed headways. One headway is 12 minutes, and another is 6 minutes. 4 timetables (distributions of arrivals) at a congestion node are provided. In all 4 cases there is no deviation from nominal headways. Timetables are illustrated with Figures 1–8 and performance measures are presented in Table 1. As nominal headway of line *L2* is the half of the nominal headway of line *L1*, line *L2* has to perform in the same planning period twice trips more than line *L1*. Timetables present the impact of nominal headways on interval synchronization.

In Case 1 (Fig. 1 and 2) the first trip of line *L1* arrives 1 minute before the first trip of line *L2*. There are no simultaneous arrivals to be observed in the timetable. The timetable is very unevenly-spaced: intervals between consecutive trips of different lines equal either 1 (from line *L1* to line *L2*) or 5 (from *L2* to *L1*).

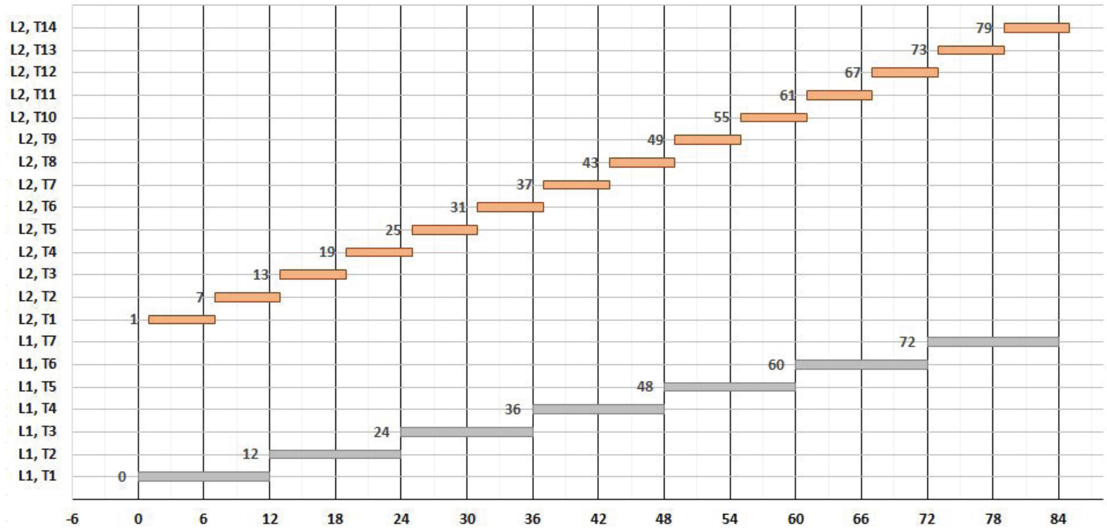

Figure 1 – Case 1: separation times. Source [16]

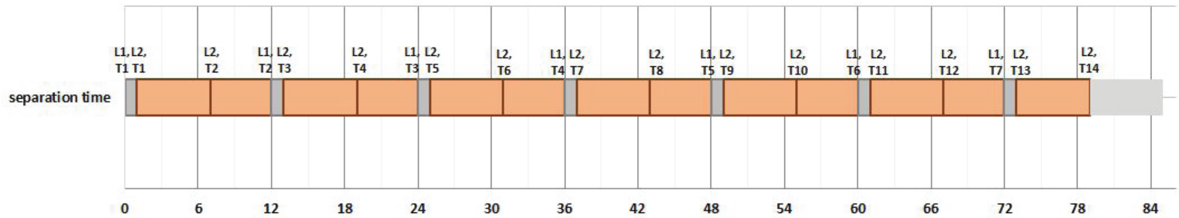

Figure 2 – Case 1: timetable. Source [16]

In Case 2 the first trip of line *L1* arrives 2 minutes before the first trip of line *L2*. There are no simultaneous arrivals to be observed in the timetable. The timetable is not evenly-spaced: intervals between consecutive trips of different lines equal either 2 (from line *L1* to line *L2*) or 4 (from *L2* to *L1*).

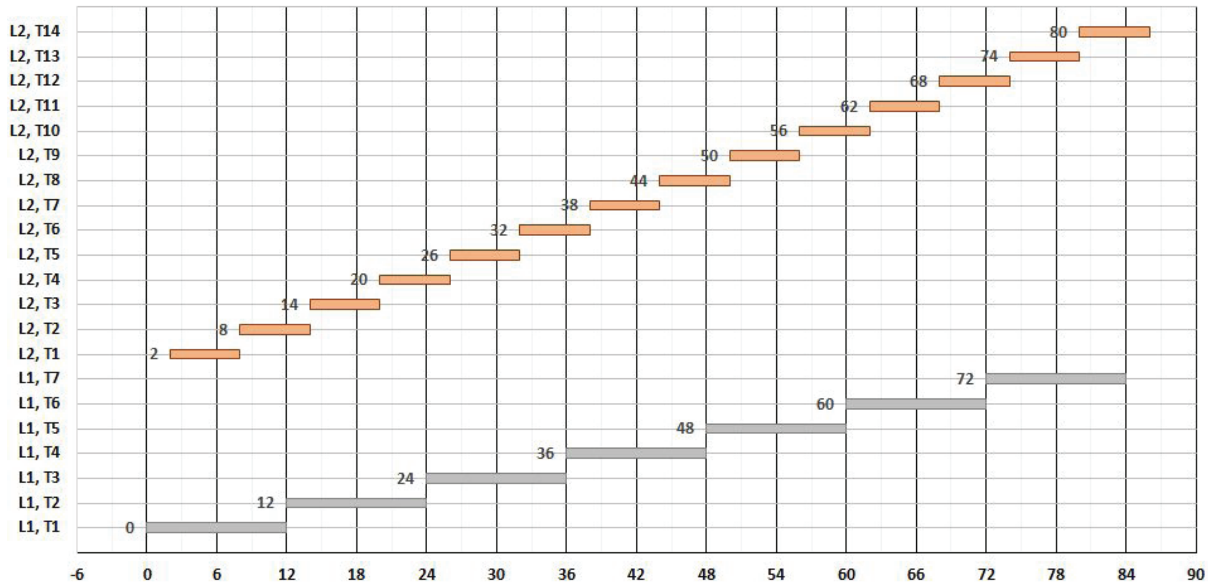

Figure 3 – Case 2: separation times. Source [16]

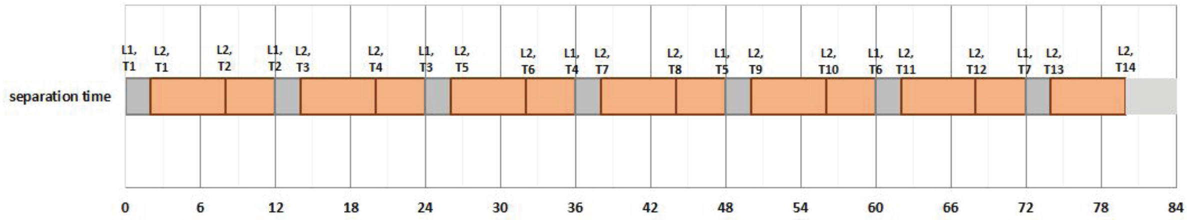

Figure 4 – Case 2: timetable. Source [16]

In Case 3 the first trip of line *L1* arrives 4 minutes before the first trip of line *L2*. The timetable is not evenly-spaced: intervals between consecutive trips of different lines equal either 2 (from line *L2* to line *L1*) or 4 (from *L1* to *L2*) – distribution of alternate arrivals is the same as in Case 2.

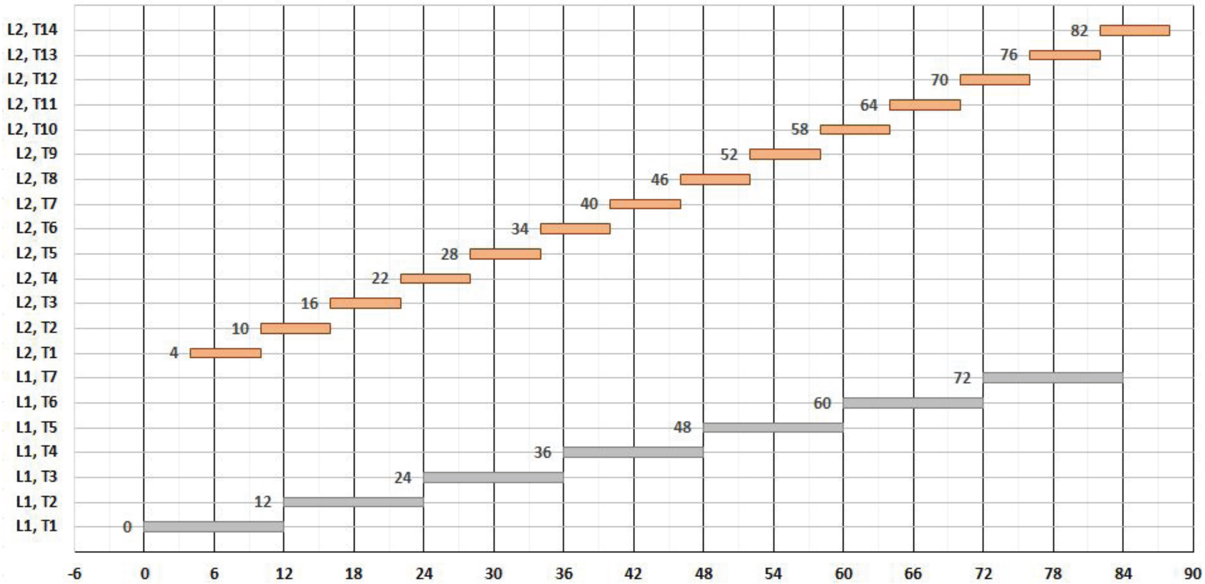

Figure 5 – Case 3: separation times. Source [16]

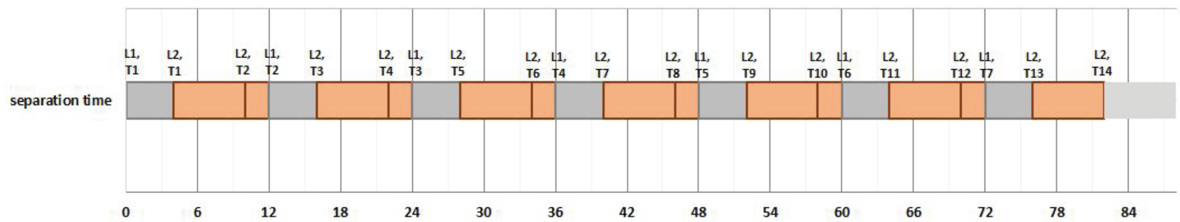

Figure 6 – Case 3: timetable. Source [16]

In Case 4 the interval between the first trips of lines equals 3, which is the half of the shorter of two nominal headways. As far as we consider intervals between arrivals of consecutive trips of different lines, the timetable is evenly spaced: every interval equals 3. However, separation times between arrivals of consecutive trips of any lines not even: they equal either 3 (between different lines) or 6 (between trips of the same line). The objective of interval synchronization is achieved – intervals between arrivals of subsequent trips of different lines are even.

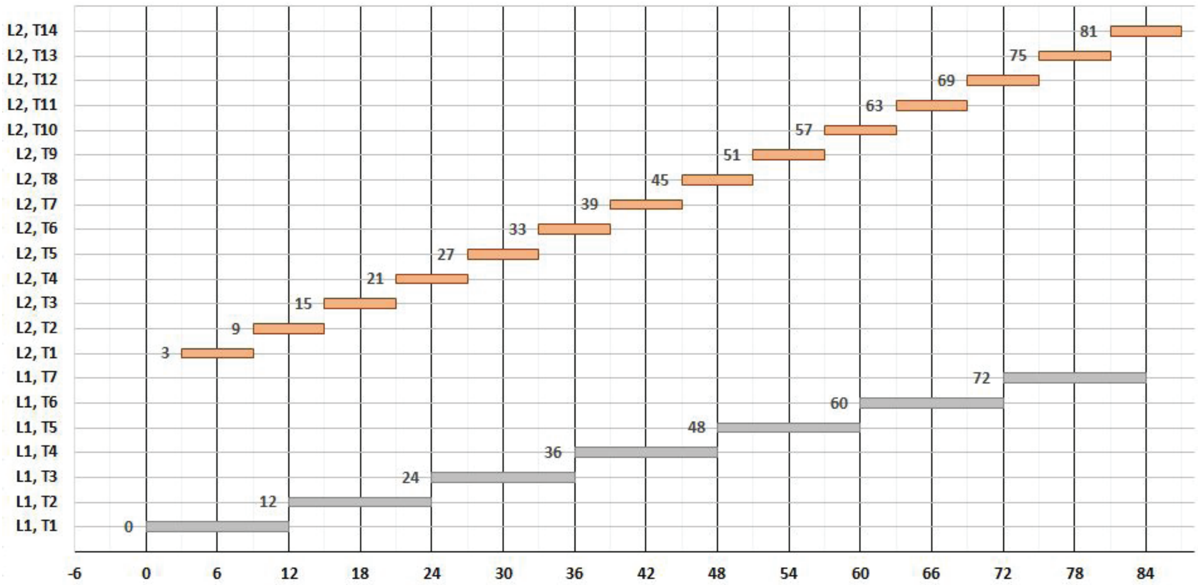

Figure 7 – Case 4: separation times. Source [16]

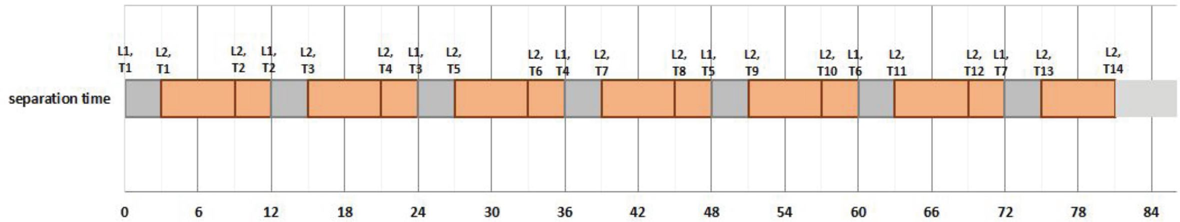

Figure 8 – Case 4: timetable. Source [16]

Performance measures collected in the Table 1 show that the lowest value of *CV* of intervals is obtained in Case 4, where intervals are even. High value of *CV* is in Case 1, where the interval between the first trips arrivals equals 1. The maximal waiting times are the same in all examples, while the maximal interval is the lowest in Case 4. The total waiting time and the total interval are the lowest in the unevenly-spaced timetable in Case 1.

Table 1 – Cases 1–4: performance measures. Source [16]

Performance measures	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Coefficient of variation of intervals between arrivals of consecutive trips of different lines (***CV***)	0.70	0.34	0.32	0.00
Maximal separation time between arrivals of subsequent trips of any lines (***MST***)	6.00	6.00	6.00	6.00
Maximal interval between arrivals of subsequent trips of different lines (***MI***)	5.00	4.00	4.00	3.00
Average separation time between arrivals of subsequent trips of any lines (***AWT***)	3.95	4.00	4.10	4.05
Average interval between arrivals of subsequent trips of different lines (***AI***)	79.00	80.00	82.00	81.00
Total separation time between arrivals of subsequent trips of any lines (***TWT***)	2.85	2.92	3.08	3.00
Total interval between arrivals of subsequent trips of different lines (***TI***)	37.00	38.00	40.00	39.00

The brief analysis of performance measures shows that the coefficient of variation of intervals between arrivals of consecutive trips of different lines is the most accurate measure for assessing timetable equalization. This performance measure indicates the fulfillment of the objective of interval synchronization: evenly spacing the arrivals of consecutive trips of different lines. Interval synchronization leads to reduction of the maximal interval between two subsequent arrivals of different lines (*MI*), however, the maximal separation time between arrivals of subsequent trips of any lines (*MST*) depends on nominal headways of synchronized lines. In the simple examples presented above, the total separation time between arrivals of subsequent trips of any lines (*TWT*), the total interval between arrivals of subsequent trips of different lines (*TI*), the average separation time between arrivals of subsequent trips of any lines (*AWT*) and the average interval between arrivals of subsequent trips of different lines (*AI*) increase with increasing equalization of timetable.

Note, that minimization of any of these measures would lead to unevenly-spaced timetables. For these reasons the coefficient of variation of intervals between arrivals of consecutive trips of different lines seems to be a suitable performance measure for assessing timetable equalization.

4. CONCLUSICE REMARKS

The majority of works devoted to this bus synchronization problem are focused on transfer synchronization which has different objectives than balancing timetable. Evenly-spaced timetables are desired usually in public transport networks with long routes served by several lines. The most commonly used performance measure – the total waiting time – is not suitable for assessing timetable equalization. Coefficient of variation of intervals seems to be the best indicator of the fulfillment of the objectives of interval synchronization. As subsequent arrivals of trips of all lines at the synchronization node should be evenly spaced in time, *CV* seems to be proper measure for assessing balancing timetables, since equalization of timetable means that intervals between two subsequent arrivals repeat the same value for as many pairs of subsequent trips as possible for a given set of synchronized lines.

5. ACKNOWLEDGEMENTS

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EVALUATION OF WAREHOUSE WITH VIRTUAL TECHNOLOGIES

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Abstract

Logistics application can greatly benefit from virtual environments. In the context of Industry 4.0 and warehouse management, virtual warehouses are an intuitive way to show and predict processes and activities in the cyber-world and real-world. To understand the dynamic behavior of the systems and verify implemented designs or processes in a time frame, the use of simulation studies are necessary. Although the amount of time and data used to produce such studies are substantial, the 3D representation of the system produces a more complete understanding of the system behavior. This paper describes the use of 3D simulation to visualize workflows in the warehouse using standardized Web techniques. It presents ongoing research of integration of warehouse managements systems and applications that supports analysis and of the evaluation of the warehouses to improve the efficiency of warehouse management. This application provides input capabilities for setting up a number of customer scenarios, and provides 3D graphical output for each. Because the application is developed to handle parameter input combinations, the user doesn't need to edit or compile model code. An XML is used as interface definitions of nodes and their behavior characteristics parameters. Automated nodes and code generation of a dynamic XML Schema simplify the implementation. Scenarios can quickly be set up and run to get comparative results and see what would likely happen in the real warehouse. Virtualization, built on Industry 4.0 design principles, can create virtual models of warehouse operations that support smarter maintenance, improved planning and process optimization.

Keywords: *virtualization, 3D simulation, warehouse, digital factory*

1. INTRODUCTION AND BACKGROUND

In this paper, we are focusing on applications of virtual environments as a part of warehouse management systems (WMS), more specific on virtual warehouse simulations as a part of trends in Industry 4.0 paradigm. From the general literature review we could identify following principles: interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity. All principles emphasize an integrated system that can provide additional services to a warehouse management applications, suggesting the best path to the unit of a required stock and providing a visual representation of the results of queries on the stocked goods. During the planning activities in a warehouse, a virtual environment could be used to provide visual checking and organize the positions of the stocked goods and in addition, it can be used to test optimizations of the warehouse. To achieve these activities a 3D model of the physical structure of the real warehouse and the positions of the goods is needed. To provide interaction in the warehouse we need navigation tools to move in the warehouse and/or to follow triggered events in the scene. Finally, this application should be conveniently accessed from common web-browsers, because typical distributed warehouses management systems are interfaced through web applications to take advantage of the Web infrastructure. To achieve these goals, we adopt the system developed for finding different design solutions using CAD systems, X3D, XML and web browsers [1]. Logistics applications for warehouse management get benefit from integration of information systems in management of warehouses and of virtual environments that represent real warehouses. Virtual warehouses enable interactions of user and analysis on distribution and movements of goods.

The management in warehouse consists of two principal decision families:

► Planning decisions on tactical level to principally concern fulfilment activity.

► Operational decisions on control level referring to routing, scheduling and order-picking activities.

This study is focusing on a tool development, which supports the planning and control decisions. According to [2], scientific research is scattered with no clear definitions and theoretical study requires conceptual and terminological foundation. Design principles are the foundation of design theory [3] and design principles support researchers to develop appropriate solutions. Companies also have difficulties (economic justification) when struggling to identify and implement Industry 4.0 scenarios and finding solutions without clear goal. From the literature review by [4] the four key components of Industry 4.0 are identified: Cyber-Physical Systems, Internet of Things, Internet of Services and Digital Factory. The most important component of Industry 4.0 is the fusion of the physical and the virtual worlds. The integration of physical and virtual worlds requests essential competence requirements in order to establish reliable integrated systems and high controlled team work [5].

The logistics, manufacturing, supply chain, and transportation industries are going through a time of rapid and transformation. The future of these industries is paved with innovation and technology.

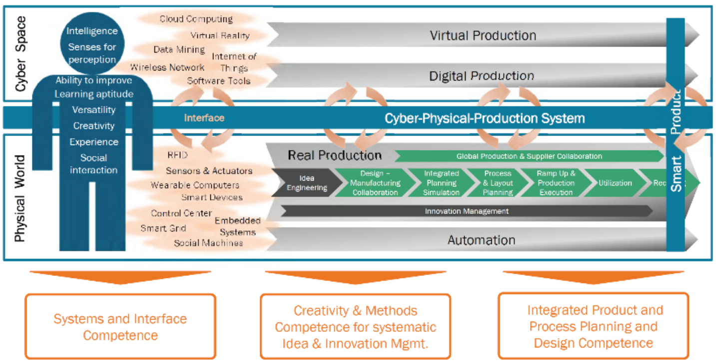

Figure 1 – Essential competence requirements [5]

Manufacturing industries can significantly increase their efficiency and productivity with the technologies that allow them to collect, process and measure big data in real time. These technologies include electronic devices that connect factories through the internet and web pages that double as dashboards for controlling the processes. Internet of Things and Internet of Services is a part of big data and predictive technology that manufacturers are already using successfully. 3D simulations of products, materials, and production processes are already used in the engineering phase of manufacturing as well as in plant operations. These simulations will leverage real-time data to mirror the physical world in a virtual model. Operators will be able to test and machine settings in the virtual world before the physical changeover. Logistics companies were among the first to adopt mobile devices to manage and monitor their processes. Initially the hand-held devices that delivery drivers used delivered benefits primarily by simplifying and automating existing paper-based processes. The planning and optimization of the layout or to rearrange layout, position of robots, machines, and transportation systems is performed efficiently by information technology tools and simulations. Using simulation techniques in design and optimization processes is known as digital factory [6], which include product development and production planning with all necessary additional systems. Digital factory concept includes designing, evaluation, monitoring and controlling the whole system in virtual 3D layout representing real facility. All potential problems found in virtual world is of crucial importance. Evaluation of the layout, checking for bottlenecks, efficiency, sensitivity to different parameters and how they affect the layout.

To provide the digital factory concept, the virtual models are necessary in order to design and explore layout, using 3D models dominantly from CAD tools. According to [7] simulation and 3D-visualisation are essential methods and tools for proper implementation of Digital Factory. 3D visualization enables much better evaluation and many times could represent aspects that is impossible to represent in 2D. The digital factory concept integrates automation of product and production process development with simulations concerning production planning and control [8].

- Discrete event based simulations of production flow planning and control in order to verify the operation planed in the virtual model for the real layout.
- Simulations of an assembly line to verify configuration definition, equipment position and balancing.
- Simulation of materials handling verify the time spending on material handling, functionality of buffer zones, distances between warehouses and production line.
- Lately, the simulations of flexible manufacturing cells are under development; e.g. robotic work cells to verify the interactions of robots with other objects in manufacturing cell, collisions with objects in cell and simulation of trajectories of robot or material movement.
- Ergonomics analyses increase safety and working conditions and consequently improves production quality and productivity.

2. MODELLING WAREHOUSE IN VIRTUAL ENVIRONMENT

Today are still some warehouses that are built around manual and paper-based processes, but the industry is overwhelmingly moving toward more automated and accelerated operations. The rise of the Industry 4.0 movement is changing the way warehouses function and are looking more like distribution centers as digital and physical architectures intersect. There are several purposes for visualization, which can be categorized as validation, analysis and marketing [9]. Displaying graphical images of dynamic behavior of a model during execution enables the user to discover errors by seeing. Following the animation of the model as it is running and comparing it with real life operation helps the user to identify discrepancies between the model and the system. In Figure 2 the real and virtualized warehouse is presented with image based modelling techniques [10]. Warehouse simulation is the computer-based modelling of a real warehousing system. Simulation enables an organization to analyze and experiment with its warehousing process in a virtual setting, reducing the time and cost requirements associated with physical testing. Storage, docks, conveyors, forklifts and even personnel can quickly be introduced and adjusted within the simulation model, allowing companies the opportunity to determine how best to fully utilize their equipment and maximize efficiency. Simulation provides a way to put a warehouse to the test in a risk-free environment without disturbing the existing warehouse system. It also enables users to determine minimum actual costs without sacrificing the required output.

Virtual environment (VE) techniques require a significant computer power to provide basic requirements, as viewing and interactions with real-time response. The problems of global cooperation over the Web are reduced with more or less specialized viewers surveyed in [11]. In order to integrate the virtual world heterogeneous data sources should be composed. At the data level, it means converting and processing different data formats. That part of the process is very important and time intensive. The process needs to raise precision of appearance and illustration, to raise presentation performance and to reduce the information loss. It has to be pointed out that virtual models are tessellated models, because only a polygonal representation allows fast rendering in a real-time.

Figure 2 – A real-world warehouse and corresponding virtual model [10]

3. INTEGRATING WMS INTO VE

The VE systems use different dataflow for manipulating virtual models in real time and converting data into the VE format is maintained differently from the system to the system, mainly depending on application [12]. With other words, the conversion is not standardized, and proposals do not exist in this direction, since in applications virtual environments functionalities vary severely. Simulation is the process of designing a model of a concrete system and conducting experiments with this model in order to understand the behavior of the concrete system and/or evaluate various strategies for the operation of the system [13]. Although the simulation experiment can produce a large amount of data, the visualization of a simulated system provides a more complete understanding of its behavior. In the visualization, key elements of the system are represented on the screen by dynamically change position as the simulation evolves through time.

In the research the focus is on automatic generation of animation of warehouse activities from CAD system modelling into X3D environment for Web-based distributed environment. The main issue is that the process automatically generates simulation for Web services and no additional knowledge or work is needed to perform simulations. To investigate and evaluate more than one solution the change of parameters is easy enough that the visualization is straight forward task.

The applications for simulation software managing problems typically presents two conflicting issues. Pure simulation applications are user friendly and lucks in flexibility and accuracy. While, simulation languages greatly improve model flexibility and accuracy, but ease-of-use is sacrificed. By utilizing a simulation language and limiting the problem domain with user friendly interface, both fields could achieve great potential. Using templates is limiting the domain of a typical warehouse layout, and the parameters implied by the data input files. These parameters include a wide range of operational functions for all areas of the warehouse. The warehouse XML model implement a lot of possible parameter combinations. The simulation provides the flexibility needed to accurately develop the warehouse model. The interface associated with the software provides for ease-of-use in setting up scenarios and running the model. The Web-based framework provides a convenient platform for users to view and evaluate a model. A distributed design system can generate design models in an XML-style feature representation to allow a Web-based system to perform viewing and manipulation, leading in two main features:

- ► Taking advantages from the effective utilizations of the Web and Java technologies makes the system independent of the operating system, scalable and service-oriented. The services located on the Internet provide an accessible way for the evaluation of warehouse activities.
- ► The configuration file represents an integrator with the definition suitable for X3D presentation.

A XML-style representation has been used to carry out some features for visualization and manipulations in the Web-based system. This format incorporates the characteristics of X3D and features to support Web applications. The XML-based information representation enables the system to be effectively adaptable to meet the new development of the Internet technology. The system and services are based on the Java-Servlet mechanism. With the development of some new Internet integration technologies such as the Web service, it is necessary to explore new alternatives to integrate the current functions under the new system infrastructure. All geometrical information, complete warehouse model with walls and shelfs configuration is extracted from the CAD system with macro programming using programming interface. X3D models generated directly from CAD systems in general are composed from many nested, complex and repeated structures. To accelerate the rendering performance of a system, a global editing of a polygonal data is necessary. The application was coded to rearrange and re-edit the X3D model; the geometry of parts is separated from appearance and additional information as view, background and navigation definitions. All data is stored in separate files. Since the direct transfer from CAD systems into X3D not exist, we use VRML transfer and convert it to X3D. The macro program was coded in order to perform all needed actions: generate the hierarchical structure in XML, separation of geometry and appearances of parts, combine separated surfaces of the part into single geometry file and perform re-editing of geometry data. The minimization of data is necessary caused by huge amount of data from modelling systems to be reduced for working on Internet applications. With DOM parser, it is possible to read the input file in XML, check formatting and semantic validity, built and present a complex hierarchical object structure with few lines of code. The configuration file represents an integrator with the definition suitable for X3D presentation. The semantic of the file is following the X3D specifications and syntax. The basic object is defined, that could be a part, a grouping element. The structure of configuration file is described in [1]. Here is shown basic approach to record the geometry specifications and added specifications for dynamic simulations. The XML file is enriched from Excel the data sheets, which is commonly used in warehouse activities description, with all necessary data for parameters to define each simulation scenario. We plan to develop an inbuilt editor that will allow easily change of parameters after every simulation run defining new scenario. For now, the change of time is considered, start time of different activities, manipulation times and moving velocity. When all the structure is completed the macro, program proceeded to simulation information. The macro appends to the configuration file the object definition of activity data with prescribed parameters with time frames.

In Figure 3 the fragments of XML file is presented accompanied with generated interpolators and route definitions.

```
<objekt ID=”WareHO”>
   <poz><scale x=”0.0010” y=”0.0010” z=”0.0010”/></poz>
   <flor ID=”warehouse_updated” inline=”Z1Z-WareHous171213.wrl”>
      <poz>   <translation x=”1000” y=”0.0” z=”0.0”/>   <rotation ang=”3.142” x=”1.0” y=”0.0” z=”0.0”/>   </poz>
   </flor>
<OrderS>
      <order ID=”ean115” locatMapp=”3L0” qu=”1” TimeMan=”0.02” prio=”1” startTime=”0”/>
      <order ID=”ean221” locatMapp=”2L0” qu=”1” TimeMan=”0.04” prio=”1” startTime=”60”/>
   …
```

```
<PositionInterpolator DEF=’ean115-PI’ key=’0, 0.4, 0.5, 0.5, 0.6, 1’ keyValue=’0 0 0, 0 7 0, -3 7 0, -3 7 0, 0 7 0, 0 0 0’/>
<OrientationInterpolator DEF=’ean115-OI’ key=’0, 0.39, 0.41, 0.59, 0.61, 1’ keyValue=’0 0 0 0,0 0 0 0,0 0 1 1.57,0 0 1 1.57,0 0 1 0,0
0 1 0’/>
<ROUTE fromNode=’WCmd115’ fromField=’fraction_changed’ toNode=’ean115-PI’ toField=’set_fraction’/>
<ROUTE fromNode=’WCmd115’ fromField=’fraction_changed’ toNode=’ean115-OI’ toField=’set_fraction’/>
<ROUTE fromNode=’ean115-PI’ fromField=’value_changed’ toNode=’TRANS115’ toField=’set_translation’/>
<ROUTE fromNode=’ean115-OI’ fromField=’value_changed’ toNode=’TRANS115’ toField=’set_rotation’/>
<PositionInterpolator DEF=’ean221-PI’ key=’0, 0.3, 0.5, 0.5, 0.7, 1’ keyValue=’0 0 0, 0 5 0, 3 5 0, 3 5 0, 0 5 0, 0 0 0’/>
<OrientationInterpolator DEF=’ean221-OI’ key=’0, 0.29, 0.31, 0.69, 0.71, 1’ keyValue=’0 0 0 0,0 0 0 0,0 0 1 -1.57,0 0 1 -1.57,0 0 1 0,0
0 1 0’/>
<ROUTE fromNode=’WCmd221’ fromField=’fraction_changed’ toNode=’ean221-PI’ toField=’set_fraction’/>
<ROUTE fromNode=’WCmd221’ fromField=’fraction_changed’ toNode=’ean221-OI’ toField=’set_fraction’/>
<ROUTE fromNode=’ean221-PI’ fromField=’value_changed’ toNode=’TRANS221’ toField=’set_translation’/>
<ROUTE fromNode=’ean221-OI’ fromField=’value_changed’ toNode=’TRANS221’ toField=’set_rotation’/>
 …
```

Figure 3 – Fragments of XML file and generated interpolators and route definitions

Finally, the configuration file is finished and at the end of the main object, the routing definitions are added. These preparations were firstly done manually with a lot of tedious and time consuming work, but when all objects and scripts are prepared, the task is not so complicated if the file structure is obeyed. To increase the efficiency of data preparation the editor will be developed to manipulate parameters in configuration file more interactively. The extended database consists of geometry, simulation definitions and the configuration file that keeps the structure of the product with attributes.

All the data are organized in files: geometry description, sensors, routing definitions, scripting nodes, interpolation data and material appearances with colors, textures, sounds etc. The objects are represented with attributes pairs; the attribute name refers to the purpose and the attribute value refers to the name of the file, which contains appropriate description to be included. The simulation run is triggered by start button to starts the simulation in browser window. During the simulation run, a full 3D animation of the warehouse scenario is shown from different viewing possibilities. This application provides input capabilities for setting up a number of customer scenarios, and provides 3D graphical output for each. Because the application is developed to handle parameter input combinations, the user don't need to edit or compile model code. Scenarios can quickly be set up and run to get comparative results and see what would likely happen in the real warehouse. The scenario is presented in Figure 4 as snapshots.

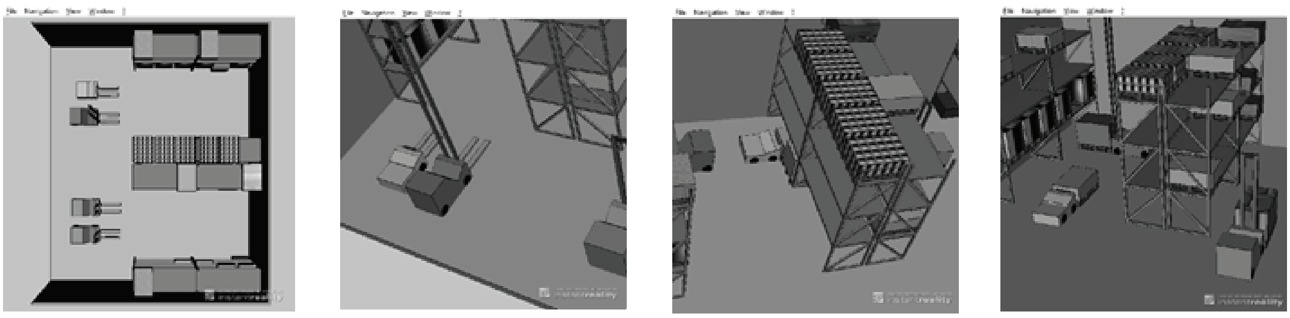

Figure 4 – Simulation snapshots of movement in warehouse

4. CONCLUSIONS

This paper is presenting straight forward approach with same details to model virtual scenes representing industrial warehouses from CAD system integrated with WMS to gather all necessary data to produce simple but adequate simulations for efficiency analysis. The approach minimizes the modelling effort and combine virtual scenes that are acceptable for simulations and similar enough to the real warehouse functionalities. The virtualization is a key component of Industry 4.0 that is available today to change warehouse management. Available solutions allows a "virtual-copy" of the warehouse to be created digitally in virtual environment merging CAD models and the warehouse information system into virtual warehouse model and simulation models. The use of simulation studies to better understand the dynamic behavior of a system under investigation is at the core of verifying models early in the development process. Despite the amount of data that such studies produce, a 3D representation of the system creates a more complete understanding of system behavior. Working on simulations improves planning, operation and maintenance by presenting a virtual view of existing conditions or modeling future conditions based on planned changes to equipment or processes. Equipment and processes in warehouse are interconnected and amplify the impact downtime of any part of equipment. With visualization it is possible to model the impact to better understand consequences on the warehouse operations and avoid unpredictable consequences. Many warehouse face challenges when introduce and implement new systems, for automation or sensors, to get full understanding of the impact of new equipment on existing processes before the equipment is installed. With virtualization it is possible to add new equipment to the virtual environment to accurately predict the impact and understand exactly what process changes are required prior the implementation to shorten deployment and startup times. For humans the visual perception of the environment is crucial. Until recently, the material handling in warehouse has been limited to a location of the product in inventory. The virtualization technology allows to monitor products as they are moving through the warehouse and improve accuracy and find opportunities for optimization. Virtualization, built on Industry 4.0 design principles, can create virtual models of warehouse operations that support smarter maintenance, improved planning and process optimization. The virtualization capabilities are changing the warehouse management.

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ECONOMIC INVESTIGATION IN VARIABLE TRANSFER BATCH SIZE, IN CONWIP CONTROLLED TRANSFER LINE

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Abstract

Production shop is a complex task that impacts the ability of an organization to integrate economic and production performance measurements. The CONWIP (CONstant Work In Process) approach is the simplest pull system to implement. Two-machine transfer lines with the exponentially distributed duration of process, break and repair were formulated and solved as a Markovian-chain. Decomposition was used to iteratively employ this solution in solving K-machine transfer line. These models assume that batch size is fixed. In this study we extend the existing transfer line solution to deal with 1 unit process batch and t units transfer batch along the line.

Keywords: *financial and economic modelling/aspects of logistics, inventory management, logistics modeling and simulation*

1. INTRODUCTION

To survive in an environment where customers require prompt deliveries, a company needs sufficient flexibility to react promptly to changes in demand. However, since manpower is one of the most expensive assets of many companies, additional staff cannot, in general attain this flexibility. Moreover, additional inventory (which is the common solution in many industries), will not be the right solution for the customer because it can cause longer lead-time (according to Little's law [3]), and less flexibility. For a fixed level of capacity, prompt reaction to changes can only be achieved when cycle times are short. Moreover, short cycle time entails low inventory and timely reaction to customers' needs.

In the literature, there are models that deal with k-machine transfer lines (KTL)[2]. Most of these models assume equal transfer batch size (TBS) and work batch size. In this study, we propose tools that deal with KTL with a difference between TBS and work batch size, under constant work in process (CONWIP) [9]. Dealing with this type of KTL is a new area, which can be useful in many practical scenarios.

Investigating the TBS is essential for several reasons:

(1) The TBS might not, and many times should not be equal to the process batch [4], [5]. The TBS is the number of units transported from one work center to another, and the process batch is the size of production or process run. When setup costs for processing and transporting are significantly different, batch sizes should be different. The idea here is to encourage LOT splitting, which in some circumstances may increase throughput.

(2) Schedules should be established by looking at all constraints simultaneously. Lead times are the result of a schedule and cannot be predetermined. Bottleneck scheduling recognizes that lead times are not necessarily fixed quantities and may vary as a function of the schedule. Note that MRP assumes that lead times between levels are fixed and known in advance [9]. Hence, the potential reduction of cycle time by decreasing TBS is negligible.

The focus of our study is to extend the existing KTL solution to permit different processing and transfer batches. Yet, we restrict the analysis to same process batch in all machines and same TBS from all machines.

The policy assumes that throughput is limited by the bottleneck machine and that there should be just enough inventories to avoid starving in the bottleneck machine. To keep inventory levels low, the material is released as late as possible to arrive at the bottleneck machine just in time to prevent bottleneck starvation [2].

2. LITERATURE REVIEW

In our work we decided to focus on transfer lines for two main reasons: (1) They are of economic importance [8], they are used in high volume manufacturing, particularly automobile production, and (2) they represent the simplest form of an important phenomenon: the interactions of manufacturing stages, and their decoupling by means of buffers [1], [2].

A transfer line is a manufacturing system with a very special structure. It is a linear network of service stations or machines (M1, M2, . . . Mk) separated by buffer storage (B1, B2... Bk-1). Material flows from outside to M1, then to B1, then to M2, and so forth until it reaches Mk, after which it leaves the system. Figure 1 depicts a transfer line. The squares represent machines and the circles represent buffers.

Each machine has its own parameters:

μ_i = process rate

P_i = failures rate

r_i = resumption rate

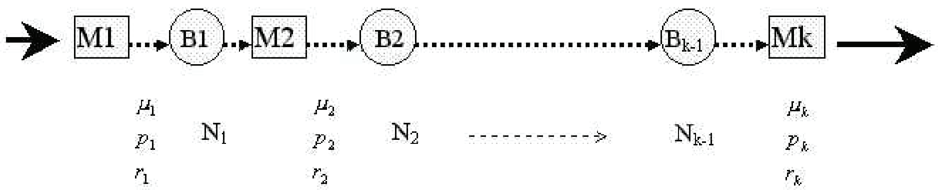

Figure 1– Structure of transfer line

If a machine's behavior was perfectly predictable and regular, there would be no need for buffers. However, all machines eventually fail, and some stations require an unpredictable, or predictable but not constant, amount of time to complete their operations. This unpredictability or irregularity has the potential for disrupting the operations of adjacent machines, or even machines further away, and buffers are used to reduce this potential. We want to assess the effects of this uncertainty on the performance of our system.

There is a lot of literature describing approaches for approximating multistage manufacturing systems. Some of them derive the performance measures of a multistage system by decomposing it into a series of two-machine line [2].

The main performance measures that are commonly used in problems that deal with manufacturing systems are: (1) Throughput: A manufacturing system's throughput is the number of parts that it produces per time unit [6]. This may be a vector if the system can make more than one-part type. It is also called production rate, (2) Work in process (WIP): WIP is the average amount of material in a manufacturing system. It is composed of the parts in the machines, in the storage areas (buffers), in the transportation subsystems and the inspection systems, (3) Cycle Time: Cycle Time is the average amount of time that a part (of a given type) spends in the manufacturing system. There is a linear link between cycle time and inventory, so, reducing one of them will reduce the other one accordingly. Cycle time is also called throughput time or lead-time. The relationship between production, or arrival, rate (λ), WIP (L), and cycle time (W) is given by Little's law [3]: L = λ*W.

Goldratt [5] said that the goal of a factory is to make money. He identify the three important measures: throughput, inventory, and operating expenses, in monetary terms rather than physical units. We will demonstrate some of our results from a financial aspect.

3. RESULTS

We will describe the result of our study from a financial analyzing point of view.

Our Objective function is:

Minimum: $T\Pi = \boldsymbol{P} \; * \Pi_i - WIP * C_{WIP} - NTIH * TRANC$

S.T:

a) The quantity of parts to be released in the releasing parts point depends on the level of the parts in the buffer in front of the bottleneck and the size of the batch.

b) The machine's processing time will be sampled from the machine's specific distribution time (deterministic, normal, and exponential).

c) The machine can be in one of four states: busy, starved, failed or blocked.

Where:

T Π = Total revenue

TP = Hourly Throughput

Π_i = unit profit

WIP = Hourly work in process

C_{wip} = WIP cost

NTIH = Number of transferring in hour (on average)

TRANC = Transfer Cost (each)

We can see that TP will be driven from the machine's production rate, availability and the percent of the time that it is blocked or starved. In the Cwip we put regular costs (material, storage, lead time, etc.). The Πi includes the selling price minus the unit working cost (manpower, machine, etc.), under the assumption that the parts that will be produced, will be sold. We chose that target function to see the difference in the costs when we change the TBS and the total level of inventory (in the first step of the analyzing we didn't take in account the transferring cost).

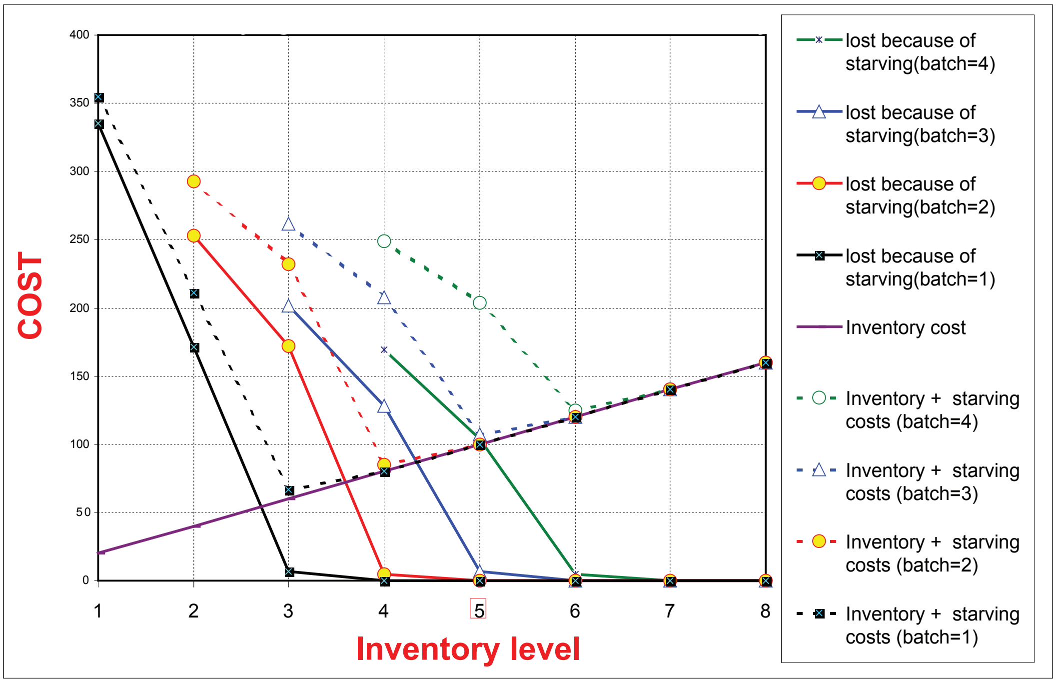

Figure 2 – Starvation and inventory costs versus TBS

In figure 2, we made our financial analyzing by checking the link between the TBS and inventory level, and the cost. We marked two kinds of costs: the linear cost that depends on the size of the inventory and cost that we defined as lost because of starving i.e., the alternative profit that we lost. We summed these costs and found some results. First, if we will start to analyze from the biggest inventory level (eight parts) to the smallest inventory level (one part), we can see that up to inventory =six parts we have only the inventory cost because we reach the maximum throughput in batch = 1,2,3, or 4. Second, when the inventory becomes smaller we can see that the cost because of starving becomes crucial, especially if we use a big TBS. For example when the inventory equals to four parts the worst choice is batch = four parts and the best choice is batch = one parts or two parts. In our experiments the best choice is inventory = three parts and the TBS equals to one part. We can notice that the minimum cost decreases if the inventory decreases.

4. SUMMARY

We began this work by emphasizing the importance of production management in new production environments. We reviewed the literature concerning production control techniques and decided to study first the Drum Buffer Rope technique, in which the focus is on the bottleneck machine. We studied the relations between the decision variables and the performance variables and the financial implications. The results of our study can support research in managing the integration of production and economic aspects in an organization. Specifically, in job shop operations, our contributing might be in analyzing both common manufacturing performance measurements as throughput, WIP, production rate and cycle time, and economical performance measurements as revenue, profit, WIP cost, and Transfer cost. The integrated perspective could be used to analyze case studies in job shop operations.

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BENEFITS OF VENDOR MANAGED INVENTORY PROGRAMS IN TWO-STAGE SUPPLY CHAINS

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Abstract

This paper investigates potential benefits of an Information Sharing (IS) scenario in a two-stage supply chain where demand for an item is generated by the AR(1) process and inventory replacements are made according to an order-up-to level (OUT) policy. To quantify such benefits, the changes in the bullwhip ratio and the average on-hand inventory level are calculated. The analysis reveals that the choice of IS scenario depends simultaneously on three factors: (a) autocorrelation level, (b) relative length of lead times, (c) the size of probability for each member to face lead time demand at most equal to his OUT level.

Keywords: *supply chain management, inventory management, forecasting, customer service, bullwhip effect*

1. INTRODUCTION

Reengineering programs in supply chains aim at balancing demand and supply with the goal of reducing the costs of inventory and stock-outs. Initiatives undertaken by members of a supply chain to negotiate information sharing is a key-success factor so that such reengineering programs are effective. With respect to these issues, the relative literature has focused for the last twenty years on the quantification of information sharing benefits.

When the demand from consumers for a single item is strongly autocorrelated and each member of the supply chain adopts the periodic order-up-to a level (OUT) policy for inventory replacement, the orders placed by a downstream member to the next upstream member are characterized by higher variability than the demand faced by the downstream member. This phenomenon is known as the “Bullwhip Effect” [1], and the “bullwhip ratio” [2] is the usual metric for measuring demand distortion in supply chains. Although the reduction of lead times from the downstream to the next upstream member mitigate the negative impacts of the bullwhip effect [3], nowadays many researchers view information sharing as the major strategy to reduce the consequences of this phenomenon.

Additionally, since 2000, a significant stream of literature has concluded that, in a two-stage supply chain with autocorrelated demand and an OUT policy for inventory replacement, letting the upstream member to have access to demand data of the downstream member could provide significant inventory reductions and cost savings to the upstream member [4, 5, 6]. This happens because having information about the demand data, the upstream member can make more accurate predictions for future orders placed by the downstream member, especially when optimal forecasting methods are adopted.

Following the aforementioned research trends, this paper investigates further if information sharing between members of a two-stage supply chain is always beneficial. In this context, it is assumed that demand at the downstream member is generated by the autoregressive model of order one, and the OUT policy for inventory replacements is adopted by both members of the chain. Two scenarios are under consideration. In the first scenario, the upstream member has no access to the demand data faced by the downstream member. On the other hand, the second scenario assumes that a vendor managed inventory (VMI) program between the members of the chain has been agreed [7,8]. The two scenarios are compared by calculating the changes in the bullwhip ratio and the average on-hand inventory level when the VMI scenario is preferred provided that inventories are kept at the downstream member's location. The analysis suggests that information sharing in the form of a VMI program is not always beneficial. In fact, three drivers affect the choice between the two scenarios; (i) the level of autocorrelation, (ii) the relative length of lead times between the two members of the chain, and (iii) the difference in the probabilities for each member to face a lead time demand at most as large as his OUT level.

Based on the above discussion and remarks this paper is organized as follows. The next section revises the OUT policy for inventory replacements when this policy is adopted by both members of a two stage supply chain. Section 3 describes the time evolution of orders placed by the downstream member when his demand data are not available to the upstream member. Section 4 explains how the upstream member makes decisions for the OUT level and the size of orders when a VMI program is agreed between the two members of the chain. The comparison between the two scenarios is discussed in Section 5 and the importance of each one of the three aforementioned drivers affecting the choice between the two scenarios is addressed. In terms of inventory and cost reductions for the total chain, Section 6 demonstrates, through a numerical example, the benefits of adopting a VMI program, when the drivers affecting the choice of such a program take on some appropriate values. Finally Section 6 concludes the paper.

2. ORDER-UP-TO-LEVEL POLICIES IN TWO-STAGE SUPPLY CHAINS

Consider a two-level supply chain consisting of one upstream member (e.g. supplier) and one downstream member (e.g. retailer). Each member of the supply chain adopts the periodic order-up-to (OUT) level policy for inventory replacement. To set up the flow of a product from the external manufacturer to the supplier and from the supplier to the retailer we adopt the timing of events which is described in [4]. In particular:

Retailer: In each time period, a non-zero demand from consumers for a single item occurs at the retailer. Let d_t be the demand occurred at the retailer during time period t with $d_t \sim N(\mu, \gamma_o)$. At the end of each time period, knowing the magnitude of demand of the period, the retailer reviews the inventory level and places an order q_t. Given that the lead time from the supplier to the retailer is fixed consisting of L_R time periods, the retailer will receive q_t at the start of time period $t + L_R + 1$, since the review interval is one time period.

Using the notation and terminology of Table 1, the OUT level of time period t is determined progressively from the following set of relationships, provided that $\sum_{m=1}^{l_R} e_{t+m|H_t} \sim N\left(0, V_{t|H_t}\right)$:

$$SS_{t+l_R} = \Upsilon_t^{(R)} - \widehat{D}_{t|H_t}, \tag{1}$$

$$Pr\left(\sum_{m=1}^{l_R} d_{t+m} \leq \Upsilon_t^{(R)}\right) = Pr\left(\sum_{m=1}^{l_R} e_{t+m|H_t} \leq SS_{t+l_R}\right) = \eta_R, \tag{2}$$

$$SS_{t+l_R} = z_{\eta_R}\sqrt{V_{t|H_t}^{(R)}}, \tag{3}$$

$$\Upsilon_t^{(R)} = \widehat{D}_{t|H_t} + z_{\eta_R}\sqrt{V_{t|H_t}^{(R)}} = \sum_{m=1}^{l_R} \hat{d}_{t+m|H_t} + z_{\eta_R}\sqrt{V_{t|H_t}^{(R)}}. \tag{4}$$

Let h_R, S_R, and C_R be the unit holding cost, the unit shortage cost and the unit purchase cost per period at the retailer. Assuming that no fixed cost is incurred when the retailer places the order and h_R, S_R, C_R are stationary over time, the minimization of a total discounted expected cost stream over an infinite horizon gives the OUT level specified in (4) with $\eta_R = \frac{s_R - c_R(1-r)}{h_R + s_R}$, where r is the discount rate [see the discussions in 3, 4]. Having determined the OUT levels $\Upsilon_{t-1}^{(R)}$ and $\Upsilon_t^{(R)}$ from (4), the retailer will order at the end of time period t

$$q_t = d_t + \left(Y_t^{(R)} - Y_{t-1}^{(R)}\right). \tag{5}$$

Supplier: The time evolution of supplier's orders to the external manufacturer depends whether the supplier has access to the retailer's demand history $H_t = \{\ldots, d_{t-2}, d_{t-1}, d_t\}$. In the current paper two scenarios are employed. In the first scenario, known as the No Information Sharing (NIS) case, the supplier has no knowledge about demand data of the retailer. In this case the supplier will make his forecasts having as demand data the retailer's orders. The second scenario refers to a situation of Information Sharing (IS) assuming that a Vendor Managed Inventory (VMI) program between supplier and retailer is agreed. According to this program the supplier takes full responsibility for decisions being made at the end of each time period. These decisions concern the determination of the OUT level and the size of orders at the retailer's point of sale (POS) where end-customer demand for the item occurs.

In the remaining of this paper a comparison between the two scenarios is performed. In accordance to Table 1, Table 2 gives notation and terminology for the supplier's ordering process. The analysis considers that demand data at the retailer's POS are generated according to the autoregressive process of order one, AR(1). This process has been extensively used in the relevant literature for modeling end-customer demand in supply chains and this has been recently justified by [5]. The authors fit ARIMA (p,d,q) models to weekly sales data over a period of two years for 1798 stock keeping units (SKU) of a major European Supermarket located in Germany. The fit of each ARIMA (p,d,q) model was made using the Time Series Expert modelling function of PASW. For each SKU the identification of the "best" model was carried out via the Normalized Bayesian Information Criterion also known as the Schwarz criterion. Under this experimental framework the authors found that in 544 SKU (30.3%) sales data were represented by the AR(1) process.

Table 1: Notation and Terminology in the retailer's ordering process

$l_R = L_R + 1$	:	Protection interval against shortages
SS_{t+l_R}	:	Safety stock just before order q_t arrives
$H_t = \{\ldots, d_{t-2}, d_{t-1}, d_t\}$	:	Historical demand data up to period t
$\hat{d}_{t+m\|H_t}$	:	The m–period ahead forecast for the true demand d_t+m, given that this forecast at period t when H_t is available
$\hat{D}_{t\|H_t} = \sum_{m=1}^{l_R} \hat{d}_{t+m\|H_t}$	:	Forecast of total demand over the protection interval l_R
$e_{t+m\|H_t} = d_{t+m} - \hat{d}_{t+m\|H_t}$	:	The m– period ahead forecast error
$V_{t\|H_t}^{(R)} = Var\left(\sum_{m=1}^{l_R} e_{t+m\|H_t}\right)$	:	Variance of the sum of forecast errors for the time interval $t + 1$ up to $t + l_R$
$Y_t^{(R)}$:	:	OUT level of period t
η_R:	:	Probability for the total demand during l_R not to exceed $Y_t^{(R)}$
z_{η_R}	:	Inverse cumulative distribution function of the Standard Normal evaluated at probability η_R

Table 2: Notation and Terminology in the supplier's ordering process

$l_S = L_S + 1$	:	Protection interval against shortages
$O_t = \{\ldots, q_{t-2}, q_{t-1}, q_t\}$	:	History of orders placed by the retailer up to period t

$\hat{q}_{t+m\|O_t}$	:	The m–period ahead forecast made by the supplier for the true order q_t+m, given that this forecast made at period t when O_t is available
$\hat{Q}_{t\|O_t} = \sum_{m=1}^{L_S+1} \hat{q}_{t+m\|O_t}$	:	Forecast of total orders over the protection interval l_S
$e_{t+m\|O_t}^{(S)} = q_{t+m} - \hat{q}_{t+m\|O_t}$	:	The m– period ahead forecast error
$V_{t\|O_t}^{(S)} = Var\left(\sum_{m=1}^{l_S} e_{t+m\|O_t}^{(S)}\right)$	:	Variance of the sum of forecast errors for the time interval $t+1$ up to $t+l_S$
$Y_t^{(S,NIS)}$:	:	OUT level of the supplier under the NIS scenario in time period t
η_S:	:	Probability for total orders during l_S not to exceed $Y_t^{(S,NIS)}$
$R_t^{(NIS)}$	:	Order placed by the supplier to the external manufacturer under the NIS scenario at the end of period t
$Y_t^{(S,IS)}$:	:	OUT level of the supplier under a the VMI scenario in time period t
$R_t^{(IS)}$	:	Order placed by the supplier to the external manufacturer under the VMI scenario at the end of time period t

3. ORDERING DECISIONS UNDER THE NIS SCENARIO

Suppose that in time period t the demand at the retailer is generated by the stationary AR(1) model

$d_t = \delta + \phi d_{t-1} + \varepsilon_t$, where $\delta > 0$, $|\phi| < 1$, and ε_t are identically and independently distributed random variables with mean zero and variance σ_ε^2. The stationary mean and variance are $\mu = \delta/(1-\phi)$ and $\gamma_o = \sigma_\varepsilon^2/(1-\phi^2)$ respectively. The true demand at time $t+m\ (1 \le m \le l_R)$ is

$$d_{t+m} = \mu(1-\phi^m) + \phi^m d_t + \sum_{j=0}^{m-1} \phi^j \varepsilon_{t+m-j}\,, \tag{6}$$

and its Minimum Mean Squared Error (MMSE) forecast is given by

$$\hat{d}_{t+m|H_t} = E(d_{t+m}|H_t) = \frac{\delta}{1-\phi}(1-\phi^m) + \phi^m d_t\,. \tag{7}$$

The following expressions give the specifications of the key-quantities which formulate the retailer's ordering process [for derivations see 3, 4, 5]:

$$\widehat{D}_{t|H_t} = l_R\mu + \frac{\phi(1-\phi^{l_R})}{1-\phi}(d_t-\mu)\,, \tag{8}$$

$$V_{t|H_t}^{(R)} = \frac{\sigma_\varepsilon^2}{(1-\phi)^2}\sum_{m=1}^{l_R}(1-\phi^m)^2 = \frac{\sigma_\varepsilon^2}{(1-\phi)^2}\left\{l_R - 2\phi\frac{1-\phi^{l_R}}{1-\phi} + \phi^2\frac{1-\phi^{2\,l_R}}{1-\phi^2}\right\}, \tag{9}$$

$$Y_t^{(R)} = l_R\mu + \frac{\phi(1-\phi^{l_R})}{1-\phi}(d_t-\mu) + z_{\eta_R}\frac{\sigma_\varepsilon}{1-\phi}\sqrt{l_R - 2\phi\frac{1-\phi^{l_R}}{1-\phi} + \phi^2\frac{1-\phi^{2\,l_R}}{1-\phi^2}}\,, \tag{10}$$

and

$$q_t = d_t + \frac{\phi(1-\phi^{l_R})}{1-\phi}(d_t - d_{t-1})\,. \tag{11}$$

Under the NIS scenario, the available data to the supplier are summarized in the set $O_t = \{\dots, q_{t-2}, q_{t-1}, q_t\}$. However, when d_t is generated by the AR(1) model, then q_t follows the ARMA(1,1) model [5]

$$q_t = \delta + \phi q_{t-1} + v_t + \theta v_{t-1}\,, \tag{12}$$

where $v_t = \frac{1-\phi^{l_R+1}}{1-\phi}\varepsilon_t$ and $\theta = -\frac{\phi(1-\phi^{l_R})}{1-\phi^{l_R+1}}$.

Since for the ARMA(1,1) it holds

$$q_{t+m} = \begin{cases} \delta + \phi q_t + v_{t+1} + \theta v_t & \gamma\iota\alpha \quad m = 1 \\ \delta \frac{1-\phi^m}{1-\phi} + \phi^m q_t + \theta\phi^{m-1} v_t + (\phi+\theta)\sum_{j=1}^{m-1}\phi^{j-1} v_{t+m-j} + v_{t+m} & \gamma\iota\alpha \quad m = 2, \ldots, \end{cases} \quad (13)$$

the MMSE forecast for the retailer's order q_{t+m} will be given by

$$\hat{q}_{t+m|O_t} = E(q_{t+m}|O_t) = \delta\frac{1-\phi^m}{1-\phi} + \phi^m q_t. \quad (14)$$

Hence the specifications for the key-quantities which formulate the supplier's ordering process will be

$$Y_t^{(S,NIS)} = \hat{Q}_{t|O_t} + z_{\eta_S}\sqrt{V_{t|O_t}^{(S)}} = \sum_{m=1}^{l_S}\hat{q}_{t+m|O_t} + z_{\eta_S}\sqrt{Var\left(\sum_{m=1}^{l_S} e_{t+m|O_t}^{(S)}\right)}, \quad (15)$$

$$\hat{Q}_{t|O_t} = l_S\mu + \frac{\phi(1-\phi^{l_S})}{1-\phi}(q_t - \mu), \quad (16)$$

$$V_{t|O_t}^{(S)} = \frac{\sigma_\varepsilon^2}{(1-\phi)^2}\left\{l_S - 2\phi^{l_R+1}\frac{1-\phi^{l_S}}{1-\phi} + \phi^{2l_R+2}\frac{1-\phi^{2l_S}}{1-\phi^2} + \frac{\phi^2(1-\phi^{l_R})^2(1-\phi^{l_S})^2}{(1-\phi)^2}\right\}, \quad (17)$$

$$R_t^{(NIS)} = q_t + \frac{\phi(1-\phi^{l_S})}{1-\phi}(q_t - q_{t-1}). \quad (18)$$

4. SUPPIER'S ORDERING DECISIONS UNDER THE VMI SCENARIO

Under this scenario, the supplier has available the data set $H_t = \{\ldots, d_{t-1}, d_t\}$ that describes the time evolution of demand at the retailer. At the end of time period *t*, knowing the size of demand, d_t, the supplier observes the inventory level at the retailer's location and places an order

$$R_t^{(IS)} = d_t + \left(Y_t^{(S,IS)} - Y_{t-1}^{(S,IS)}\right), \quad (19)$$

to the external manufacturer. The retailer will receive this order at the beginning of time period $t + L_S + 1$. Two crucial remarks should be emphasized at this point. First, since the order is given from the supplier to the external manufacturer for the sake of the retailer, the lead time is not L_R but L_S. Second, since inventories are kept at the retailer's location, the unit holding and shortage costs per time period refer to the retailer. These remarks lead to the following specifications of the key-quantities describing the ordering process:

$$\hat{Q}_{t|H_t} = \sum_{m=1}^{l_s}\hat{d}_{t|H_t} = l_S\mu + \frac{\phi(1-\phi^{l_S})}{1-\phi}(d_t - \mu), \quad (20)$$

$$V_{t|H_t}^{(S)} = \frac{\sigma_\varepsilon^2}{(1-\phi)^2}\left\{l_S - 2\phi\frac{1-\phi^{l_S}}{1-\phi} + \phi^2\frac{1-\phi^{2l_S}}{1-\phi^2}\right\}, \quad (21)$$

$$Y_t^{(S,IS)} = \hat{Q}_{t|H_t} + z_{\eta_R}\sqrt{V_{t|H_t}^{(S)}}, \quad (22)$$

$$R_t^{(IS)} = d_t + \frac{\phi(1-\phi^{l_S})}{1-\phi}(d_t - d_{t-1}). \quad (23)$$

5. EVALUATION OF THE IS-VMI SCENARIO AGAINST THE NIS SCENARIO

In the currents section we evaluate the merit of the VMI scenario using the following two criteria: (a) mitigation of the consequences of the "bullwhip effect", and (b) the reduction in the average on-hand inventory level. Under the NIS scenario, the impact of bullwhip effect is measured by the ratio [3]

$$BW_t^{(NIS)} = \frac{Var(q_t)}{Var(d_t)} = 1 + 2\phi \frac{(1-\phi^{l_R})(1-\phi^{l_R+1})}{1-\phi} . \tag{24}$$

On the contrary, for the VMI scenario, the ratio takes the form

$$BW_t^{(IS)} = \frac{Var\left(R_t^{(IS)}\right)}{Var(d_t)} = 1 + 2\phi \frac{(1-\phi^{l_S})(1-\phi^{l_S+1})}{1-\phi} . \tag{25}$$

Regarding the second criterion, [4] gives an approximate expression to measure the average on-hand inventory level. Under the NIS scenario, for the retailer, this expression takes the form

$$AOH_{NIS}^{(R)} \approx \frac{\delta}{2(1-\phi)} + z_{\eta_R}\sqrt{V_{t|H_t}^{(R)}} , \tag{26a}$$

while for the supplier the approximate expression for the average on-hand inventory will be

$$AOH_{NIS}^{(S)} \approx \frac{\delta}{2(1-\phi)} + z_{\eta_S}\sqrt{V_{t|O_t}^{(S)}} . \tag{26b}$$

Employing the VMI scenario, for both the retailer and the supplier, it holds

$$AOH_{VMI} \approx \frac{\delta}{2(1-\phi)} + z_{\eta_R}\sqrt{V_{t|H_t}^{(S)}} . \tag{27}$$

Thus, a second criterion to quantify potential benefits of the VMI scenario for the retailer and the supplier is represented respectively by the size of the differences

$$\Delta I^{(R)} = AOH_{NIS}^{(R)} - AOH_{VMI} \approx z_{\eta_R}\left(\sqrt{V_{t|H_t}^{(R)}} - \sqrt{V_{t|H_t}^{(S)}}\right) , \tag{28a}$$

and

$$\Delta I^{(S)} = AOH_{NIS}^{(S)} - AOH_{VMI} \approx z_{\eta_S}\sqrt{V_{t|O_t}^{(S)}} - z_{\eta_R}\sqrt{V_{t|H_t}^{(S)}} . \tag{28b}$$

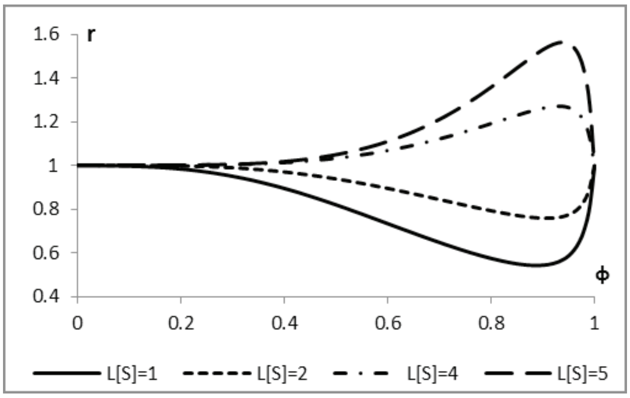

Figure 1: Graph of r as function of ϕ for $L_R = 3$

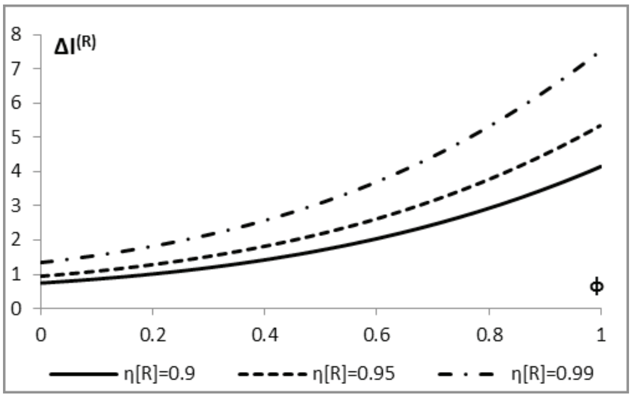

Figure 2a: Graph of $\Delta I^{(R)}$ as function of ϕ, $L_R = 3$, $L_S = 1$

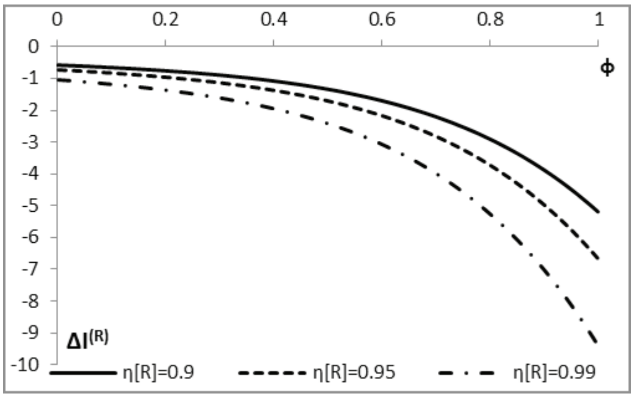

Figure 2b: Graph of $\Delta I^{(R)}$ as function of ϕ, $L_R = 3$, $L_S = 5$

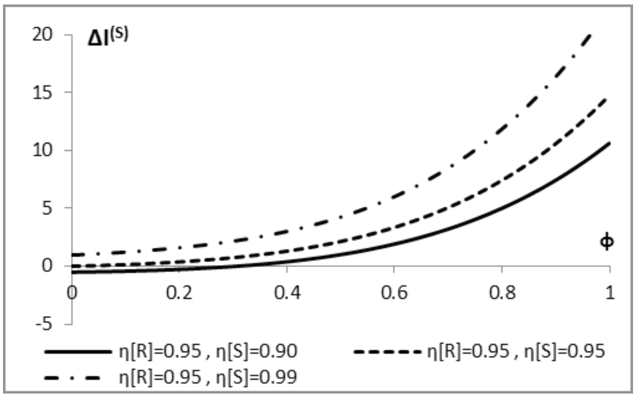

Figure 3a: Graph of $\Delta I^{(S)}$ as function of ϕ, $L_R = 3$, $L_S = 1$

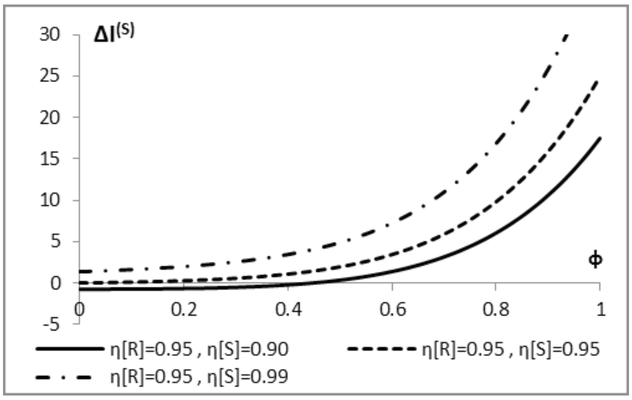

Figure 3b: Graph of $\Delta I^{(S)}$ as function of ϕ, $L_R = 3$, $L_S = 3$

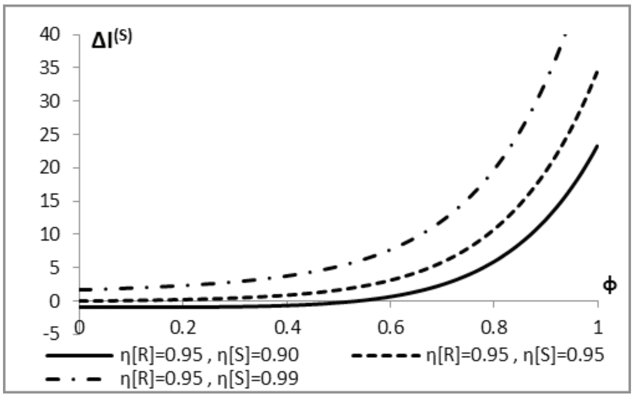

Figure 3c: Graph of $\Delta I^{(S)}$ as function of ϕ, $L_R = 3$, $L_S = 5$

From the retailer's side, and for different probabilities, η_R, of not stocking out during the protection interval L_R, Figures (2a) and (2b) display inventory changes when ϕ is getting larger setting without loss of generality $\sigma_\varepsilon^2 = 1$. From the two graphs, there is strong evidence that when $L_R > L_S$ then VMI is beneficial for the retailer as inventory reductions are getting larger with either higher values of ϕ or greater sizes of η_R. On the contrary, when $L_R = L_S$ the VMI scenario does not have any impact on inventories while for the case where $L_R < L_S$ the retailer is experiencing increasingly larger inventories when end-customer demand becomes more heavily autocorrelated or η_R is getting larger.

Regarding the supplier, when $\eta_S \leq 0.5$ and $\eta_R > 0.5$, it is straightforward from (28b) that for any L_R, L_S negative values for $\Delta I^{(S)}$ are taken, supporting in that way the NIS scenario. On the contrary, when both η_S and η_R exceed 0.5, the sign of $\Delta I^{(S)}$ is not easily determined. For this case, Figures (3a), (3b) and (3c) display the graph of $\Delta I^{(S)}$ as function of ϕ for different pairs of values (L_R, L_S) having set again $\sigma_\varepsilon^2 = 1$. From the three graphs it is verified that when $\eta_S > \eta_R$, for any pair of values (L_R, L_S) positive values for $\Delta I^{(S)}$ are taken supporting under such circumstances the VMI scenario. For the case, however, where $\eta_S < \eta_R$ it is not certain that the sign of $\Delta I^{(S)}$ will be always positive. Nonetheless, starting with $L_R > L_S$ and keeping L_R fixed, by increasing L_S the sign of $\Delta I^{(S)}$ becomes positive for relatively higher values of ϕ which gradually become closer to unity.

6. A NUMERICAL EXAMPLE

In this section, the sizes of inventory and cost reductions for the two levels of the supply chain when a VMI program is agreed between the retailer and the supplier are demonstrated by using a numerical example. The analysis is focused for the special case where $L_R > L_S$ and $\eta_R < \eta_S$. The choice of parameter values was made according to the framework which was set by [7]. Particularly, for the AR(1), we set $\delta = 20$, $\phi = 0.8$, and $\sigma_\varepsilon = 9$. The values of the remaining parameters are displayed in Table 3.

Under the NIS scenario, using (26a) and (26b) respectively, it is computed an average on-hand inventory of 114.37 units for the retailer and 125.62 units for the supplier. Adding up the products of each average on-hand inventory and the corresponding holding cost given in Table 1, it is obtained for the chain as a whole a total holding cost of 354.36 monetary units. Given, however, that an agreement between the supplier and the retailer for a VMI program has been succeeded, by replacing the aforementioned parameter values into (27), it is found out that the amount of inventory at the retailer's location is reduced to 80.48 units. Since inventories are kept to the retailer's location, the holding cost is reduced to 160.97 monetary units. Furthermore with the NIS program the bullwhip ratio has a magnitude of 4.16, while with the VMI program this ratio decreases to 2.41.

It is concluded therefore that the adoption of a VMI program between the retailer and the supplier drops for the chain as a whole the inventories by 66.5% and the holding cost by 54.6%. Besides, the negative impacts of the bullwhip effect are reduced by 42.4%.

Table 3: Values of Parameters

	Retailer	Supplier
Lead time	$L_R = 3$	$L_S = 1$
Holding cost	$h_R = 2$ monetary units	$h_S = 1$ monetary units
Probability of not stocking out	$\eta_R = 0.95$	$\eta_S = 0.90$

7. CONCLUSIONS

This paper considers a two-stage supply chain with its members to be identified as "retailer" and "supplier". The demand faced by the retailer is described by the AR(1) process. Inventory replacements are made by both members according to the periodic order-up-to a level policy. The time evolution of the supplier's orders from an external manufacturer is investigated adopting two scenarios. The first scenario considers that the supplier does not have access to retailer's demand data. The second scenario assumes an Information Sharing situation where a Vendor Managed Inventory (VMI) program has been agreed by the two members, provided that inventories are kept at the retailer's location. The case of VMI program is evaluated according to two criteria related to reductions (a) of consequences of the bullwhip effect and (b) in the average on-hand inventory level at both the retailer's and supplier's locations. The analysis shows that only under certain conditions the VMI program is beneficial for both members of the supply chain. These conditions depend on the length of lead times, the probability for each member not to experience a stock-out during the protection interval and the level of autocorrelation demand.

More specifically, the VMI program brings benefits to both the retailer and the supplier only in the case where the retailer's lead time L_R is greater than the supplier's lead time L_S and simultaneously the supplier's probability η_S of not stocking out during the protection interval $L_S + 1$ is at least equal or greater than the corresponding retailer's probability η_R. If L_R keeps to be greater than L_S but $\eta_R > \eta_S$, benefits for both members still exist provided that end-customer demand is heavily autocorrelated. On the contrary if $L_R < L_S$ and $\eta_R \leq \eta_S$ only the supplier is experiencing benefits for a VMI program. Finally, only for the case where $L_R > L_S$, reductions of the negative impacts of the bullwhip effect are observed.

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GREEN LOGISTICS AND ITS TOOLS SUPPORTING THE MAIN ASSUMPTIONS OF GREEN ARCHITECTURE

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Abstract

The article discusses the purpose of Green Logistics and its importance in implementing the primary objectives of Green Architecture as one of the determinants of sustainable development. The reduction of costs and energy inputs in the construction business has a direct impact on the economic sector and contributes to the environmental protection. The article aims to indicate the possible benefits resulting from the implementation of the Green Architecture principles based on the assumptions of Green Logistics favouring the pro-environmental attitude. As we witness numerous environmental threats and energy crises, sustainable development and favorable Green Logistics become a priority for economic growth, including construction, a sector that receives a large part of the capital. Therefore issues such as cost control, control of energy indicators of the facilities, use of the climate specificities, appropriate technology or local, but improved building materials – biomaterials are not without significance.

Keywords: *green logistics, green Architecture, sustainable development, energy-saving, low-energy objects*

1. INTRODUCTION

The subject matter of the work is related to two problematic trends. The first is associated with the idea of Green Architecture and the second with Green Logistics. It is difficult to discuss Green Architecture, without mentioning the threat to the environment or the way of shaping architectural objects, consistent with the assumptions of sustainable design. These aspirations set contemporary trends in the creation of a built environment that complies with the natural environment through, among others, low energy consumption, preservation of biodiversity, and the pursuit of user's satisfaction. A helpful tool to achieve this goal is the BIM standard, a design tool already required in many countries, which allows for full control of processes related to the life of objects.

The efficiency of construction projects depends on logistics services, responsible for providing the necessary materials, equipment, financial resources and information on the course of design and construction works. The BIM standard applied in the construction sector, and project activities facilitates the coordination of the indicated actions. Therefore this tool is also of great importance for Green Logistics executed in the field of construction and architectural design – creating eco-friendly architecture, consistent with the assumptions of Green Architecture. As a supporting instrument, it manages the flow of information about the facility and industry works, the schedule of these works and costs related to the whole design phase, maintenance of the facility and its demolition. It also allows creating mechanisms characteristic for full logistics activities including both the design stage and the construction phase.

In the face of the ongoing degradation of the environment, we have to acknowledge the need to implement pro-environmental solutions that favour the preservation of the appropriate state of nature, as well as the health condition of people. Hence, it is necessary to sensitise society to the indicated problems. It seems, however, that higher social awareness about the poor management of the environment, including the impact of manufacturing industry on the balance of the natural resources has a chance to result in increased interest in the problem of sustainable development and Green Logistics. It can also contribute to the achievement of economic, social and environmental goals, which refer to the assumption of Green Architecture. It should be emphasised that environmental policy is based on the principles of sustainable development, including, among other things, concern for the resources and diversity. These activities are possible to implement by meeting key objectives of Green Architecture related to Green logistics.

Ecological logistic is applied in many economic sectors, not only construction, which results in the promotion of its main assumptions. The fundaments of this concept include low energy consumption and low emission of pollutants during production, storage and transport, lowering costs and protecting the environment. The already mentioned BIM standard is beneficial to control the discussed processes. Apart from the coordination of design works, it creates the construction schedule and controls energy indicators, essential for energy-saving building, already required in many countries. Another important advantage of BIM is the control of construction, operation and demolition costs. The agenda of works, including the simplest tasks such as waste disposal, the operation of vertical and horizontal transport equipment at the construction site, internal communication, coordination of dates and places of supply, safety and health protection are vital for logistic tasks during the implementation of construction activities [1]. Green Logistics introduces modern organisational forms of the logistic management [2]. They rely on undertaking activities of planning, organising, and controlling processes in such a way that the goal of the adopted strategy in the area of logistics is achieved. For example, they may result in minimising the costs of logistics services for a construction project, improvement of the quality of logistics services (timeliness of deliveries), maximising value added, etc. [3]. Efficient management requires skilful supervision of logistics processes, supported by tools developing a strategy and a way of its implementation, taking into account the changing trends in the economy. It seems that in this context the BIM standard is particularly useful, especially since it concerns scale of the impact of the facility on the environment during the whole cycle of its functioning (life cycle assessment). The BIM process allowing for the analysis of the effects of architecture on the environment provides an objective judgment regarding the outcomes of the interaction between the elements of natural and built environment. Therefore, it is essential to skilfully use climatic factors in the planning and shaping of buildings. Microclimatic conditions include natural and anthropogenic factors taking into account the geometry of urban layouts, local heat sources and topography of the area. In the micro-urban scale, these dependencies can be analysed with regard to the spatial development of the building's surroundings, the location, the type of the terrain, its orientation and shape, including the form of the roof covering and the spatial arrangement of the building.

Logistic management in the design and construction sector is aimed at controlling investment and its impact on the natural environment. In addition, it allows making important decisions related to the control of flows in an enterprise or ventures which are part of the logistic process. For instance, skilful management allows making optimal choices, e.g. regarding the mode and size of the orders. However, the investor must be aware of the impact of individual elements of the logistics on the supply costs (purchase, transport, asset freeze, etc.) [4].

Logistic management is also directly related to the creation of the so-called eco-calculator that among other things, allows measuring, energy consumption during, for instance, the production of building materials, their transportation and use throughout the construction. Throughout the operation of the object, the energy factors that the facility uses when absorbing energy from the natural solar radiation are vital. Such calculations make it easier for the architects who are using computer simulations, to use meteorological factors characteristic of given climate zones to design architectural objects with almost zero energy consumption. Green Architecture that remains in harmony with the natural environment is already supported by the indicated standards and the Green Logistics applicable in many sectors of the economy. It aims to reduce the adverse impact of production, logistics and other activities on the environment. This attitude is fostered by pro-ecological actions, applied, for example, in the spatial development, allowing efficient functioning of the city, its infrastructure and spaces of various characters. This process also affects the shaping and perception of architecture that strives to meet the principles of Green Architecture, whose international nature and application determine its importance. It enables activities characterised by care for the environment and its resources so that they can serve future generations. The idea of Green Architecture also generates the so-called social benefits. It corresponds with the aspirations aimed at providing pro-health conditions for contemporary people, conducive to the proper psycho-physical well-being of a person. The improvement of the quality of the environment in the health-oriented area can also be achieved through the activation of the community, creating common spaces of a social nature that strengthen interpersonal relationships.

2. THE CONCEPT OF GREEN ARCHITECTURE

Although the meaning of this concept is slightly different than assumed in colloquial use, it draws attention to the need of improvement of the living conditions – a higher standard of human life, with a simultaneous concern for over-exploited natural resources. This issue is not a simple one, especially as it concerns the lives and needs of, as indicated by the data from 2016, over 7.3 billion people (7323 million) [5]. The number of inhabitants is relevant to the scale of the problem of the interference in the environment, especially since human activity has a significant impact on the preservation of the natural assets. Man is the perpetrator of the transformation of the natural environment, which as a result of his activity, undergoes various alterations. Due to the ongoing changes in the natural world, such as climate conditions, we face the obligation to prevent the destructive phenomena. This notion is a part of the idea of sustainable development, which counteracts the social and economic crisis. Initiatives connected with sustainable development implement the principles of sustainable, including the foundation of Green Architecture. It affects not only project activities that are in harmony with the natural environment but also supports bioclimatic comfort and pro-health conditions of the living environment. In order to maintain these conditions, we must take into account, among others, the geo and hydro-biotronic parameters, isotherms of the predicted temperature distribution in relation to the plutonic heat of the Earth. The biotronic analysis takes into account the data defining the location of the geopathic zone and the extent of the "N" area with the most intense radiation harmful to the human organism (from 6 to 10 of the BIO scale). Biotronic measurements also refer to the determination of the radiation range of the geological structures as well as those originating from the flow of sub-water [6]. It should be noted that the radiation of the electric fields does not always have a negative effect on humans, as positive fields have favourable results. Implementation of the principles of Green Architecture is not easy due to the individual scope of the introduced changes and because of the scale of the planned activities. It should also be emphasised that this concept does not bring immediate results; it requires long-term activities, for example, in the field of education that raise social awareness and sensitise social groups to global problems related to poor management of the natural resources. The concept of Green Architecture also affects, to a certain extent, the quality of life, the comfort of the living environment, and decides about the holistic approach to the natural environment of man and his needs. It also emphasises the contact with nature and with biologically active areas, limited due to the increasing intensity of the building development. Today, the view from the window and the possibility of walking the alleys of the nearby park determines the prices of the apartments. The idea of sustainable design or the Green Architecture expresses concern for the psychological and physical condition of the human, hence the important role of social participation in the process of change. The involvement of social groups seems to be crucial as it largely determines the success of the transformations within the urban fabric, which consists of the morphological system, the legal structure determining the way the city functions, as well as social, functional, climatic, physiognomic and spatial structures. Social groups satisfied with the populated place, willingly identify themselves with their environment, try to maintain its proper condition and culture by taking care of all its elements. Each structure is included in the notion of the Green Architecture, which refers not only to the natural environment (morphological and climatic structure, etc.) but also to the processed environment (anthropogenic and artificial), counteracting its degradation. The impact of these environments and their elements create a place to live and thus must be considered as significant. Special importance in building a "healthy" relationship between the natural and the man-built environment is attributed to ecological architecture interpreted as one of the elements of the ecosystem that remains in harmony with nature throughout its entire lifecycle. It is also necessary to analyse the costs of the existence and functioning of the object covering the full life cycle, in order and to determine the impact and its scope on the environment, and vice versa. It promotes a pro-health character of the living environment, which is to enable the implementation of a healthy lifestyle and maintain a proper psycho-physical condition [8].

Table 1 – Green Urbanism. Own study based on a summary of P. Haupt upon Lehmann's assumptions [3]

Green Urbanism		
Green architecture	**Relations with the natural environment**	**Transportation**
- the use of new technologies and construction systems allowing for the increase of biologically active spaces (green roofs, walls) - the use of ecological materials - object orientation consistent with the parts of the world - the use of local material resources – a reduction of transport costs - cost reduction related to the material production - economical management of the natural resources - low energy consumption - the use of renewable energy sources	- taking into account the morphology of the urban structure - applying optimal distances (shading of the objects) - taking into account the climatic conditions in shaping the interiors - the proximity of the natural elements - adaptation to the parts of the world - climate change management - air humidity regulation	- restrictions of individual transport in favour of collective, pedestrian and bicycle transport - provision of a communication space to increase the safety - reduction of the inconvenient communication outcomes (vibrations, noise, air pollution)

In order to maintain the idea of Green Architecture, which determines the high quality of the housing environment, it is necessary to take into account the climatic conditions. They are important because of the relationship between the spatial development of urban fabric and the natural elements of the environment. Climatic factors such as sun exposure, thermal conditions, humidity and the possibility of ventilation have a different range of impact on a macro (regional), meso (city) and micro (neighbourhood) scale. The effect of the individual climate elements on a macro level is presented in table number 3. A specific type of climate is valid for each of the sites considered in the macroscale. Apart from the geographic location, factors such as the typology of the development, the size of urbanised areas, the type and density of buildings are of importance. On the macroscale, the characteristics of the climate zone in which the given region is located are significant. In the meso – city scale – mesoclimatic phenomena are taken into consideration, i.e., solar radiation, temperature, air circulation and water balance. On the local and microscale (district, housing estate and building quarter with the closest surroundings), microclimatic phenomena occurring in the roof layer, including, among others, insolation (Table 4) are considered.

Table 2 – The impact of individual climate elements on a macro scale, taking into account their parameters. Based on K. Zielonko – Jung [10]

SCALE OF IMPACT	CLIMATE ELEMENT	PARAMETERS
Macroscale	Sun exposure	location - geographical region, size of the city, number of the inhabitants, building typology, building density, the ratio of the area built to the open, afforestation, industrialisation
	wind	temperature -5 – necessary wind protection 25 – insufficient ventilation state of the atmosphere characteristic of the analysed area, urban layout - the ratio of the area, meteorological conditions characteristic for the region
	temperature/ water balance	the level of population, size of the region, size of the built-up areas

Table 3 – Influence of solar radiation on a micro scale including its parameters. Based on K. Zielonko– Jung [11]

Influence of solar radiation on a micro (urban interior/building quarter) and its parameters
Parameters
location concerning the parts of the world – slope of the area relative to the sun
type of building
compactness of the building development
the height of the building development
the geometry of the building development: sky exposure: SV. 0,2 (at lower consignation), 0.4 – up to two storeys
canyon coefficient: h / s (usually on the microscale 0.75-1.5)
the distance between buildings
distance to the wooded area - shadow effect
percentage of the hardened surface
type of the surface (matte, reflective)
surface colour (light, dark)
accumulation capacity on this scale, with a small number of trees 1-2j (m^2k) / s
surface albedo -albedo on the 0.1-0.2 surface, average demand for heating and cooling

3. GREEN LOGISTICS AND BIM SYSTEM

The BIM system as a tool taking into account all investment stages and logistic works connected with an architectural object. It controls the process of creating a concept, preliminary project of planned investment, design phase, as well as analysis of the object’s functioning and its use. Therefore it is possible to prepare future renovations of the facility and its operating costs. Logistics tasks are essential at every stage of the investment cycle [12] (Table 4).

Table 4 – Logistics tasks in the investment cycle based on Sobatka A.[13]

Phase	**Logistics task**
Programming	Checking the concept of the venture in the aspect of logistics. Defining a logistics strategy in the concept of project management
Design	Analyses of alternative construction and material solutions. Material specifications. Development of logistics concepts and feasibility studies. Development of logistic guidelines for tender documentation of quality systems necessary for logistics services
Planning	Development of schedules for construction and resource demand, logistic concepts at the construction site, a project of development and liquidation of the construction site. Guidelines for the purchase or leasing of construction equipment. Collection and selection of suppliers' offers. Planning logistic processes (models and control methods). Evaluation of the economic efficiency of logistics and environmental impact. Planning waste logistics
Implementation	Updating of schedules and delivery plans. Customizing orders to the current demand for resources. Planning and coordination of horizontal and vertical transport on a construction site. Unloading, (possibly reloading) and storage of materials. Division and completion of loads for individual contractors. Implementation of logistic quality service systems. Documenting the effects of efficient innovations in the logistics of the project. Waste disposal. Exploitation of IT systems supporting logistics management. Coordination of logistic processes of all contractors
Hand-over to operation	Liquidation of the construction site, management of information flow. Analysis of logistic tasks throughout the investment and construction cycle shows that number tasks at the design and planning stage are similar to the number of tasks during the implementation phase

Building Information Modelling or Building Information Management is a tool supporting the project phase. It enables to maintain a database of the building and helps to plan a possible change of its parameters using the appropriate software supporting the design process. The system allows for management of the information about the site, controls it and decides on the way of using the area, including its full investment documentation. This possibility is provided by the skilful use of data collected by BIM. Quick changes are made owing to the conservative scenarios stored by the system. Similarly, BIM also enables the user to manage the value of the real estate through the access to collected data about equipment and finishing. The system generates a comprehensive report of thorough analyses.

The advantages of BIM also include the substantial savings of the investment. Although the cost of the system implemented in the design stage is higher by 2-3%, in the later stages, it decreases even up to 50%, while the minimum increase in savings reaches up to 20%. Another benefit is the improvement of the quality of investments, including the control of its impact on the elements of natural and built environment. A comparison of selected benefits of BIM application is presented in Figure. 1.

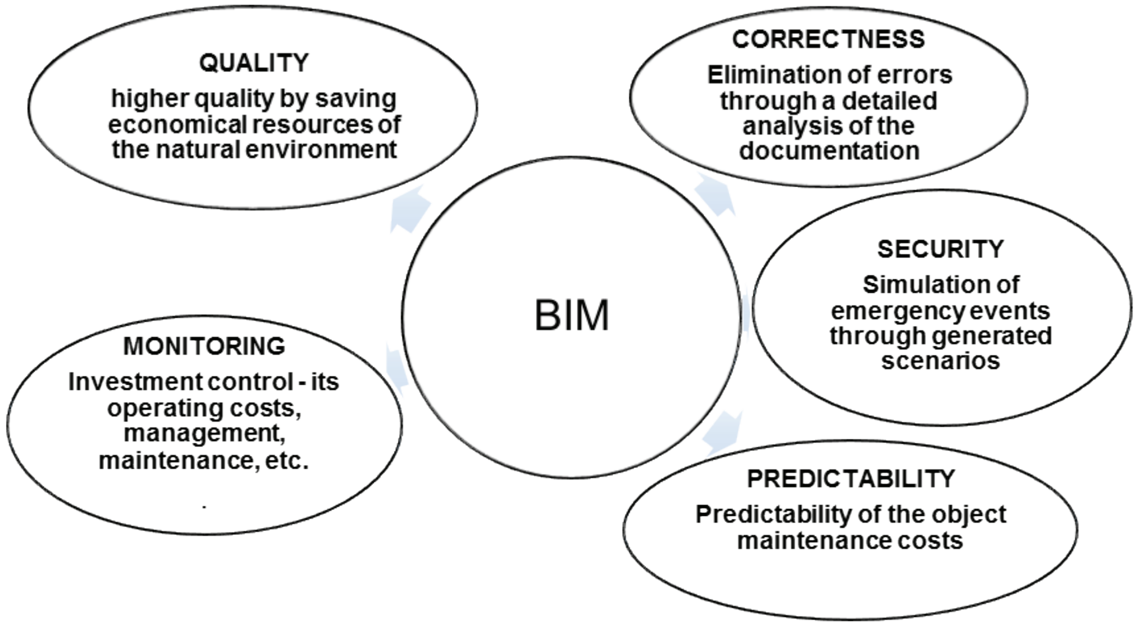

Figure 1 Selected benefits of the BIM system. Own study based on A. Tomana [7]

4. CONCLUSIONS

Green Architecture is a concept of a broad application, the usefulness of which, as well as the timeless value, should be seen in the concern for the state and resources of nature, and the living conditions of modern man. The Green Logistics is important for shaping Green Architecture objects, taking into account the construction and operation costs of the facility, the schedule of design and construction works and the way buildings interact with the environment. An appropriately planned logistic system and efficient management allow for success in the implementation of investment and the reduction of costs related to logistics and the entire project. The decrease in expenses is significantly influenced by the method of managing the flows of resources from the supplier to the recipient and the coordination of logistic processes of participants of the investment [15]. "It facilitates the integration of logistic processes and the outsourcing of logistics services to specialised organisations. This approach allows to solve many technical and organisational problems, protect the natural environment, shorten the construction cycle and, as a result, reduce the economic and social costs of the project. Another important factor that allows increasing the efficiency of logistics management is the use of modern IT communication technologies (integrated IT systems, EDI system – electronic data exchange, funds transfer, remotely controlled transport, etc.)"[16]. It should be emphasized that the idea of Green Architecture is favoured by the availability of the green areas, close contact with natural elements and recognition of the existing climatic conditions, such as sun exposure, thermal balance, air circulation, as well as humidity. Adapting to the parameters of the indicated climatic factors can improve the living conditions. Their inclusion in the formation of the architecture of a certain height, the maintenance of appropriate distances between the buildings, adaptation of the glazing forms of buildings and roofing are some of the key issues enabling the shaping of bioclimatic architecture close to the natural environment. The control over the relations between natural and built environment is carried out by the BIM system, which not only prevents the destruction of the natural environment but also leads to savings in the use of its resources and costs related to the maintenance of architectural structures. Green Architecture prevents spatial and environmental problems associated with housing areas at their various scales. It sets the directions of aspirations aimed to improve the quality of the housing environment, taking into account the principles of sustainable development, being a safeguard against excessive exploitation of nature. Moreover, it uses climate conditions for rational planning and locating the facilities in the residential environment, adapting them to the existing natural conditions. It seems that Green Architecture is one of the most important concepts that may be useful for planning not only present but also upcoming, ideal housing concepts.

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PERFORMANCE ANALYSIS OF SHUTTLE-BASED STORAGE AND RETRIEVAL SYSTEMS VERSUS MINI-LOAD AS/RS

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Abstract

In this paper throughput performance analysis of Shuttle-Based Storage and Retrieval Systems (SBS/RS) versus mini-load AS/RS is presented. Mini-load AS/RS exist in the market for nearly 50 years or more. There are several designs (single- or multi-shuttle) of mini-load AS/RS. The throughput performance of the mini-load AS/RS is limited by the number of cycles per hour (FEM 9.851), which cannot cope with today's e-commerce order fulfilment services. For this reason, major material-handling providers have introduced to the market a new technology known as SBS/RS, which enables higher throughput, flexibility and scalability. According to the throughput performance analysis for the selected cases, SBS/RS will be properly evaluated and discussed.

Keywords: *logistics, automated warehouses, SBS/RS, performance analysis*

1. INTRODUCTION

The logistics costs have an important influence on the business success of companies. Representing on average around 10% of sales in western companies, costs of logistics operations in industrial systems can play a vital role in determining the competitiveness of a company. The efficiency and effectiveness of logistics of a company are largely determined by design of logistics systems and operations performed in such systems. Warehousing systems are one of them [4]. Generally, warehouses are needed for the following reasons: (i) An imbalance in the flow and outflow of goods due to the inappropriate dynamics of production and consumption, (ii) Taking goods from numerous producers for the production of combined shipments, (iii) The realization of the daily supply of goods in the production and distribution, (iv) The realization of additional activities, such as packaging, final assembly [1]. One of the important material handling systems in warehouses is represented by Automated Storage and Retrieval Systems (AS/RS). In general, there are two types of AS/RS; the traditional, Crane-Based AS/RS (CB AS/RS) and the relatively new Autonomous Vehicle Storage and Retrieval Systems (AVS/RS). CB AS/RS consist of Storage Racks (SR) along aisles, Storage and Retrieval machines (S/R machines), accumulating conveyors, Input / Output locations (I/O locations), buffers, etc. AVS/RS consist of accumulating conveyors, SR, lifts (elevators) and autonomous vehicles. Autonomous vehicles storage and retrieval systems can be divided for unit-load (pallets) and for totes handling. The latter is also known as Shuttle-based storage and retrieval systems. The throughput performance of the SBS/RS as a whole includes both the elevator's lifting table and shuttle carrier's performance [2], [3], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16]. Estimating the throughput performance of the SBS/RS is an essential step in SBS/RS design. One way to improve the throughput performance is to finding the proper shape of tiers and columns and the velocity profile of the lift and shuttles for a given SBS/RS capacity. In this paper, the proposed model for the throughput performance calculations of SBS/RS is presented.

2. SBS/RS AND MINI-LOAD AS/RS

Shuttle-based storage and retrieval systems (Figure 1) consist of the elevator with a lifting table that is moving in the vertical direction and is feeding the Storage Rack (SR). The elevator's lifting table has its own drive for vertical movement. The elevator's lifting table operates on single and double command sequence. The storage rack consists of columns (*C*) in the horizontal direction and tiers (*M*) in the vertical direction. At the beginning of each tier is a buffer position, where totes are delivered by the elevator's lifting table. Delivered totes wait for a shuttle carrier to be transferred in the storage rack. In each tier of the storage rack is a single tier-captive shuttle carrier that is traveling in the horizontal direction. The shuttle carrier is an automatic vehicle with four wheels and has its own drive for horizontal movement. The shuttle carrier operates on single and double command sequence, as well [7], [8], [9], [10], [11], [12].

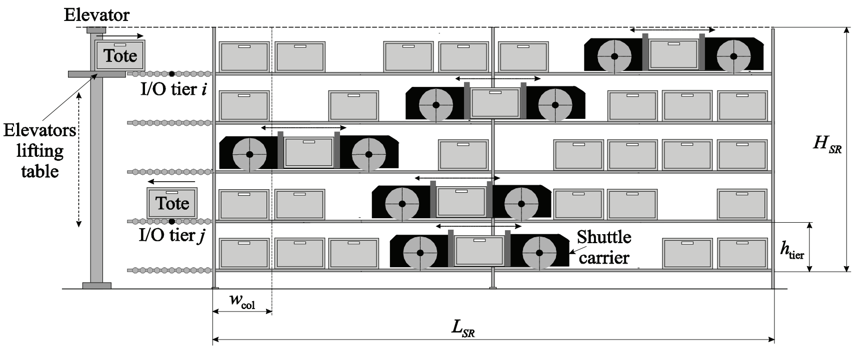

Figure 1 – SBS/RS (side view) [8]

Compared to SBS/RS, mini-load AS/RS consist of storage racks (SR), storage and retrieval machine (S/R machine), input and output (I/O) locations and interface conveyors. The S/R machine can move simultaneously in the horizontal and in the vertical direction by using the hoisted carriage. The throughput performance of the mini-load AS/RS depend of the proper length and the height of the SR and the velocity profile of the S/R machine. The mini-load AS/RS are fully computer controlled, which collect beneficial information and provide a high degree of inventory visibility, which can be further used for manufacturing and distribution processes.

The storage and retrieval sequencing of the SBS/RS are based on the following transactions. For the storage transaction the elevator's lifting table starts from the ground-floor, i.e., the first tier. The elevator's lifting table picks up the tote and moves to the designated tier. When the elevator's lifting table reaches its destination, it releases the tote in the buffer position. The shuttle carrier in the designated tier picks-up the tote from the buffer position. The shuttle carrier travels with the tote to the designated storage location and releases it in the storage location [12].

For the retrieval transaction the shuttle carrier in the designated tier moves to the retrieval location to pick-up the tote, and then travels to the buffer position. The shuttle carrier releases the tote in the buffer position. The elevator's lifting table moves to the designated tier and picks up the tote from the buffer position. The elevator's lifting table moves to the I/O point (first tier) with the tote and releases the tote [12].

The assumptions that were used in the SBS/RS modelling are summarized as follows [7], [8], [9], [10], [11], [12]:

- ► The SBS/RS is divided into storage racks on both sides (left and right), therefore totes can be stored at either side in i^{th} tier.
- ► The I/O location is located at the first tier of the SR.
- ► The dwell-point location of the tier-captive shuttle carrier in the i^{th} tier of the SR (when idle) is located at the I/O_i buffer position.
- ► The storage rack is divided by columns (*C*) and tiers (*M*).

- At each tier of the storage rack, there are two buffer position (left and right) and a single tier-captive shuttle carrier.
- The elevator with the elevator's lifting table is feeding the SR with totes.
- The elevator and shuttle carriers work on a Single Command (SC) and on Double Command (DC) modes.
- The sequences of (*i*) Acceleration, constant velocity and deceleration and (*ii*) Acceleration and deceleration have been used.
- The tier-captive shuttle carrier travels simultaneously in the horizontal and vertical directions.
- The drive characteristics of the elevator's lifting table, as well as the height H_{SR} of the SR, are known in advance.
- The drive characteristics of the tier-captive shuttle carrier, as well as the length L_{SR} of the SR, are known in advance.
- The height H_{SR} of the SR is large enough for the elevator's lifting table to reach its maximum velocity v_{max} in the vertical direction.
- The length L_{SR} of the SR is large enough for the tier-captive shuttle carrier to reach its maximum velocity v_{max} in the horizontal direction.
- A randomized assignment policy is considered which means that any storage location is equally likely to be selected for storage or retrieval location to be processed.

We summarize the acronyms and notations in the paper as in below [7], [8], [9], [10], [11], [12]:

AS/RS	Automated storage and retrieval systems.
CBAS/RS	Crane based automated storage and retrieval systems.
S/R	Storage and retrieval.
SR	Storage rack.
I/O	Input and output.
AVS/RS	Autonomous vehicle storage and retrieval systems.
SBS/RS	Shuttle based storage and retrieval systems.
SCAR	Shuttle carrier.
LIFT	Elevator's lifting table.
CO_2	Carbon dioxide.
SC	Single command.
DC	Dual command.
T	Time.
v	Velocity.
a	Acceleration / deceleration.
$v(t)$	Velocity in dependence of time.
v_{max}	Max. velocity.
M	Number of tiers.
C	Number of columns.
l_{tote}	Length of the tote.
w_{tote}	Width of the tote.
h_{tote}	Height of the tote.
l_{COM}	Length (depth) of the storage cell.
w_{COM}	Width of the storage cell.
h_{COM}	Height of the storage cell (tier).
v_x	Velocity of the shuttle carrier in the horizontal direction.
v_y	Velocity of the elevator's lifting table in the vertical direction.

a_x Acceleration/deceleration of the shuttle carrier in the horizontal direction.
a_y Acceleration/deceleration of the elevator's lifting table in the vertical direction.
H_{SR} Height of the storage rack.
L_{SR} Length of the storage rack.
$T(SC)_{LIFT}$ Expected single command cycle time of the elevator's lifting table.
$T(DC)_{LIFT}$ Expected dual command cycle time of the elevator's lifting table.
$T(SC)_{SCAR}$ Expected single command cycle time of the shuttle carrier.
$T(DC)_{SCAR}$ Expected dual command cycle time of the shuttle carrier.
$\lambda(DC)_{LIFT}$ Throughput capacity of the elevator's lifting table based on DC.
$\lambda(SC)_{LIFT}$ Throughput capacity of the elevator's lifting table based on SC.
$\lambda(DC)_{SCAR}$ Throughput capacity of the shuttle carrier based on DC.
$\lambda(SC)_{SCAR}$ Throughput capacity of the shuttle carrier based on SC.
$\lambda(DCC)_{SBS/RS}$ Throughput capacity of the SBS/RS as a whole.
$\lambda(SC)_{AS/RS}$ Throughput capacity of the mini-load AS/RS based on SC.
$\lambda(SC)_{AS/RS}$ Throughput capacity of the mini-load AS/RS based on DC.
η Efficiency.
τ Bottleneck.
$t_{P/S\ LIFT}$ Pick-up and set-down time of the elevator's lifting table.
$t_{P/S\ SCAR}$ Pick-up and set-down time of the shuttle carrier.
Q Warehouse volume.

3. THROUGHPUT PERFORMANCE CALCULATIONS OF SBS/RS

Throughput performance of the SBS/RS is inversely dependent from the cycle time of the elevator's lifting table and shuttle carriers. Cycle time of the SBS/RS is based on the analytical travel-time model, which is based on the assumption on a non-constant velocity time distribution and the probability theory [7], [8], [9], [10], [11], [12].

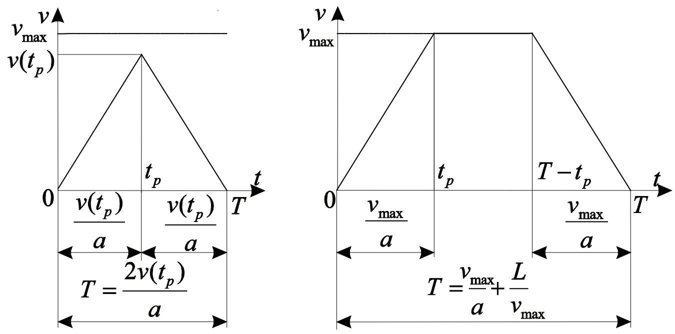

Figure 2 – Non-constant velocity-time relationship [8]

3.1. Travel-time model of the SBS/RS

Single command cycle – shuttle carrier and elevator's lifting table

The expected single command cycle time $E(SC)_{SCAR}$ [2] of the shuttle carrier equals expression (1).

$$E(SC)_{SCAR} = 2 \cdot t_{P/S\,SCAR} + 2 \cdot \frac{v_x}{a_x} + \frac{L_{SR}}{v_x} \text{ (sec.)} \tag{1}$$

By considering (1) the throughput performance $\lambda(\mathrm{SC})_{\mathrm{SCAR}}$ [2] of the shuttle carrier is calculated by (2):

$$\lambda(\mathrm{SC})_{\mathrm{SCAR}} = \frac{3600}{E(\mathrm{SC})_{\mathrm{SCAR}}} \left(\frac{\text{totes}}{\text{hour}}\right) \tag{2}$$

The expected single command cycle time $E(\mathrm{SC})_{\mathrm{LIFT}}$ [2] of the elevator's lifting table equals expression (3).

$$E(\mathrm{SC})_{\mathrm{LIFT}} = 2 \cdot t_{\mathrm{P/S\,LIFT}} + 2 \cdot \frac{v_y}{a_y} + \frac{H_{SR}}{v_y} \ (\text{sec.}) \tag{3}$$

By considering (3) the throughput performance $\lambda(\mathrm{SC})_{\mathrm{LIFT}}$ [2] of the elevator's lifting table is calculated by (4):

$$\lambda(\mathrm{SC})_{\mathrm{LIFT}} = \frac{3600}{E(\mathrm{SC})_{\mathrm{LIFT}}} \left(\frac{\text{totes}}{\text{hour}}\right) \tag{4}$$

Double command cycle - shuttle carrier and elevator's lifting table

The expected double command cycle time $E(\mathrm{DC})_{\mathrm{SCAR}}$ [2] of the shuttle carrier equals expression (5).

$$E(\mathrm{DC})_{\mathrm{SCAR}} = 4 \cdot t_{\mathrm{P/S\,SCAR}} + 3 \cdot \frac{v_x}{a_x} + \frac{4}{3} \cdot \frac{L_{SR}}{v_x} \ (\text{sec.}) \tag{5}$$

By considering (5) the throughput performance $\lambda(\mathrm{DC})_{\mathrm{SCAR}}$ [2] of the shuttle carrier is calculated by (6):

$$\lambda(\mathrm{DC})_{\mathrm{SCAR}} = \frac{3600}{E(\mathrm{DC})_{\mathrm{SCAR}}} \cdot 2 \left(\frac{\text{totes}}{\text{hour}}\right) \tag{6}$$

The expected double command cycle time $E(\mathrm{DC})_{\mathrm{LIFT}}$ [2] of the elevator's lifting table equals expression (7).

$$E(\mathrm{DC})_{\mathrm{LIFT}} = 4 \cdot t_{\mathrm{P/S\,LIFT}} + 3 \cdot \frac{v_y}{a_y} + \frac{4}{3} \cdot \frac{H_{SR}}{v_y} \ (\text{sec.}) \tag{7}$$

By considering (7) the throughput performance $\lambda(\mathrm{DC})_{\mathrm{LIFT}}$ [2] of the elevator's lifting table is calculated by (8):

$$\lambda(\mathrm{DC})_{\mathrm{LIFT}} = \frac{3600}{E(\mathrm{DC})_{\mathrm{LIFT}}} \cdot 2 \left(\frac{\text{totes}}{\text{hour}}\right) \tag{8}$$

4. ANALYSIS

In this section, main input data for the analysis are provided. Stock keeping unit represents a tote filled with items with the following dimensions: length $l_{\mathrm{tote}} = 0.6$ m, width $w_{\mathrm{tote}} = 0.4$ m and height $h_{\mathrm{tote}} = 0.24$ m. Concerning the tote, the storage compartment (cell) has the following dimensions: length (depth) of the storage cell $l_{\mathrm{COM}} = 0.6$ m, width of the storage cell $w_{\mathrm{COM}} = 0.5$ m and height of the cell (tier) $h_{\mathrm{COM}} = 0.5$ m. Dimensions of the SBS/RS storage rack (L_{SR} and H_{SR}) depends on the number of columns C in the horizontal direction and number of tiers M in the vertical direction, respectively.

Three different SBS/RS configurations were analysed based on three values of tiers M ($M_1 = 10$, $M_2 = 15$ and $M_3 = 20$) and three values of columns C ($C_1 = 167$, $C_2 = 112$ and $C_3 = 84$). Based on the number of tiers M and number of columns C, the capacity (warehouse volume) of the SBS/RS is as follows: $Q_{\mathrm{SBS/RS\ 1}} = 3340$ totes ($M_1 \cdot C_1 \cdot 2$), $Q_{\mathrm{SBS/RS\ 2}} = 3360$ totes ($M_2 \cdot C_2 \cdot 2$) and $Q_{\mathrm{SBS/RS\ 3}} = 3360$ totes ($M_3 \cdot C_3 \cdot 2$). Velocity profile of the shuttle carrier were set to $v_x = 3$ m/s and $a_x = 2$ m/s^2 and for the elevator's lifting table $v_y = 5$ m/s and $a_y = 6$ m/s^2. Pick-up and set-down times were set to 3.0 second for the shuttle carrier and 1.5 second for the elevator's lifting table.

For the mini-load AS/RS, one configuration was analysed according to FEM 9.851 [17] and based on one configuration of tiers and columns ($M = 80$ and $C = 20$). Based on the number of tiers M and number of columns C, the capacity (warehouse volume) of the mini-load AS/RS is as follows: $Q_{AS/RS}$ = 3200 totes ($M \cdot C \cdot 2$). Note that the capacity of the mini-load AS/RS is similar to the above capacities of the SBS/RS. Velocity profile of the S/R machine were set to v_x = 3 m/s and a_x = 2 m/s^2 and for the hoisted carriage v_y = 2 m/s and a_y = 1,5 m/s^2. Pick-up and set-down times were set to 3.0 second for the S/R machine and for the hoisted carriage. Based on the cycle-time and throughput performance calculation (Spielzeitenberechnung für Hochregallager) [18] according to FEM 9.851 [17], the throughput performance of the mini-load AS/RS is as follows: $\lambda(SC)_{AS/RS}$ = 167 totes/hour and $\lambda(DC)_{AS/RS}$ = 202 totes/hour.

Table 1 – Throughput performance of the SBS/RS based on single command cycle

No.	$\lambda(SC)_{SCAR}$	$\lambda(SC)_{LIFT}$	η_{SCAR}	η_{LIFT}	τ	$\lambda(SC)_{SBS/RS}$
1	980*	635	0.65	1.0	lift	635
2	1950**	584	0.30	1.0	lift	584
3	3140***	540	0.17	1.0	lift	540

*980 = 98 totes/tier · 10 tiers; **1950 = 130 totes/tier · 15 tiers; ***3140 = 157 totes/tier · 20 tiers

Table 2 – Throughput performance of the SBS/RS based on dual command cycle

No.	$\lambda(DC)_{SCAR}$	$\lambda(DC)_{LIFT}$	η_{SCAR}	η_{LIFT}	τ	$\lambda(DC)_{SBS/RS}$
1	1340*	732	0.54	1.0	lift	732
2	2610**	686	0.26	1.0	lift	686
3	4100***	645	0.16	1.0	lift	645

*1340 = 134 totes/tier · 10 tiers; **2610 = 174 totes/tier · 15 tiers; ***4100 = 205 totes/tier · 20 tiers

According to the results presented in Table 2 and 3, the throughput performance of the SBS/RS is influenced by the number of tiers M, number of columns C, the velocity of the elevator's lifting table (v_y, a_y) and the velocity of the shuttle carriers (v_x, a_x). The system performance mainly depends of the performance of the elevator's lifting tables, which is feeding the storage racks. Since a shuttle carrier can handle more work than the elevator, the assumption of tier-captive shuttles could be released in the future work.

5. FINAL REMARKS

The aim of this study is to present the basic analytical models that can estimate the throughput performance of the selected SBS/RS. Various factors of SBS/RS were examined such as: Velocity (v), acceleration / deceleration (a), length (L_{SR}) and height (H_{SR}) of the storage rack. In all cases the throughput performance of the SBS/RS is much higher compared to the mini-load AS/RS, which is limited with 101 double command cycles per hour ($\lambda(DC)_{AS/RS}$ = 202 totes/hour), and can note cope with today's e-commerce order fulfilment services. This study can be extended with (i) Different velocity and acceleration / deceleration scenarios for the elevator's lifting table and the shuttle carrier, (ii) Different configurations of SBS/RS, (iii) Application of the environment aspects like energy consumption and CO_2 emissions may also be considered in the analysis.

6. ACKNOWLEGEMENTS

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A SIMULATION-BASED ANALYSIS OF TRAIN DESIGN SPEED FOR URBAN RAIL TRANSIT SYSTEMS

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Abstract

This paper analyzes the factors related to train operational speed. An analytical framework to evaluate the consequences of different design speeds is proposed to determine the rational speed. Based on the train simulator developed by the authors, the paper presents the concrete results of two urban rail lines. From the viewpoint of train operation and passenger journey efficiency, the paper concludes that increasing train design speed in central areas, where the distance between stations is not long enough, is not necessary as energy consumption may boost much rapidly.

Keywords: *transportation, transportation management, logistics modelling and simulation, design speed*

1. INTRODUCTION

In recent years, more and more Chinese megacities have been planning to build urban rail network to avoid the road traffic jams in urban areas with high population density. As a result, a dozen of cities have opened railway service whilst another dozen of cities are building urban railway systems. During the planning and design process, both engineers and city officials express a strong hope to increase the train speed from commonly accepted 80km/h to greater level such as 100km/h or even more [1].

The increase of train speed is much attractive for most megacities which have suffered serious traffic jams. However, the increase of train design speed greatly may elevate the cost of the whole urban rail system. Previous researches show that the investments of system with 100km/h will be 25% higher than those of 80km/h [1]. It is necessary to explore the systematical consequences of the speed increment and thus to judge the significance of the increment.

Table 1 lists the commercial speeds of several urban rail systems in European cities [2]. The design speed of train, i.e. maximum train speed, these cities are at 80km/h.

Table 1 – Commercial train speeds in several European cities (km/h)

Speed\City		Paris	London	Madrid	Barcelona	Athens
Average commercial speed	Bus	15	18	14.7	16.5	17.5
	Light Rail	-	24	-	-	-
	Subway	24	33	25	28	30
	Heavy rail	43	57	-	38.6	58.8

Nong [3] studied the maximum design speed based on the case of Line 3 in Guangzhou City, China, where four different maximum speed scenarios of 80km/h, 100km/h, 120km/h, and 140km/h was considered. Line 3 in Guangzhou is 28.5km long with 13 stations and its average distance between stations is 2.4km.

This paper discusses the various impacts of train design speed on the construction and operation of urban rail systems. Based on the General-purposed Train Movement Calculator developed by Hong Kong Polytechnic University [4,5,6], authors developed a multi-train simulator [7] in the State Key Laboratory of Rail Traffic

Control and Safety. This paper also gives a series of performance data based on two practical urban rail lines in Beijing and Shanghai under the different scenarios of train speeds at 80km/h, 100km/h and 120km/h by the developed simulator. Several technical and engineering remarks are concluded in the end of the paper for a higher efficiency of urban rail operation.

2. OPERATIONAL EFFICIENCY OF URBAN RAIL SYSTEMS

The maximum design speed is the speed restriction which the train will probably manage to reach during its journey. The increase of the maximum speed may heighten the average train speed directly, decrease the number of vehicles required under the certain level of service and provide better service of rail transport for passengers. Anyway, the quantitative results about the increment of the maximum train speed require other detailed analysis under some specified transport environment.

The maximum speed of many domestic and oversea urban railways is set to 80km/h [1]. Higher maximum speeds for trains in operations need the better track qualities in whole rail systems, including large-radius curves, level gradients and large-space tunnels, which may greatly add the infrastructure investment of the rail system. Besides, the improvements of signal systems may also lead to more investment.

There are two aspects related to the operational efficiency of urban rail systems. First, an efficient rail system should offer passengers a satisfactory trip service on travel speed, comfort, safety et al. Second, the system should also be both economically acceptable and technically reliable during its construction and operations for transport suppliers. As one of the crucial factors related to the operational efficiency, the maximum train speed can not only boost the travel efficiency for passengers, but also enlarge the investment of transport suppliers. Figure 1 describes the factors and their balance between disadvantages and advantages.

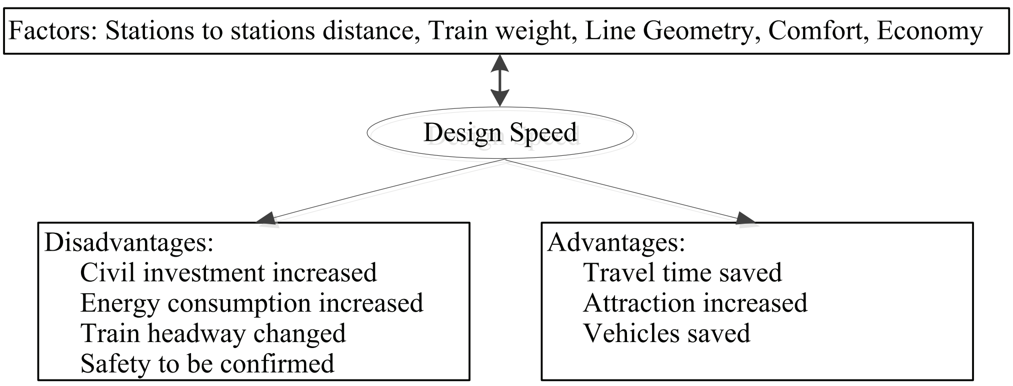

Figure 1 – System Analysis to the Determination of Maximum Train Speed

It is well known that the maximum train speed at design level is the maximum speed which trains can approach during their movement. This speed does not necessarily mean the high commercial speed for passengers to perceive in their travels. In practice, the average travel speed related with the journey time probably attracts passengers more, which may be dependent on several main factors below.

2.1 Station to station distance

The distance between stations is one of the most important factors to affect train commercial speed in a rail transit system. The longer the distance between stations, the greater the average speed that train can achieve. In most urban areas, the station-station distances of rail transit systems range from 500m to 2,000m for a satisfactory accessibility and the better attraction to passengers. That is why most urban railways take the 80km/h as their design speed of trains. In some suburb railways, it is possible to take higher maximum train speeds as the station-station distance may reach 2 to 5 km [2].

2.2 Train weight and its formation

In urban railways, the traction of trains is comparatively stable because of its fixed train formation. The loading rate of urban trains is generally greater than that of intercity trains as the former needs to accommodate some stand-up passengers. The consideration for the safety of stand-up passengers, rail sector restricts the maximum starting and stops accelerations during train movements. It is also a constraint factor for train to approach the maximum design speed within some short distances, especially in the case of short train headway with strict safety requirements.

2.3 Line geometry

Usually, rail transit lines in urban areas have more curves and greater gradients [8]. These will affect the train speed profiles in train operations. Traditionally, the factors which restrict the train speed involve curves, switches, gradients, bridges and crossings. Some Chinese engineers suggested applying linear motor train under the condition, where the vehicle wheels only play a role of supporting and bearing the weight of the train, because there is no mechanical transmission and the traction is not restricted by the factor of rail adherence any more. Thus, the vehicles have stronger dynamic performance and especially more outstanding grade ability. The linear motor vehicles use radial bogies, which can improve the stability of a train when it passes a curve.

The calculation expression of the speed restriction on curve, V_r, is generally given as below:

$$V_r = a\sqrt{R} \tag{1}$$

Where R denotes the radius of the curve and a denotes a coefficient related to the performance of train bogies and passenger comfort.

2.4 Passenger Comfort and Economic Characteristics

Compared with intercity trains, urban trains have smaller formations and headways. Some limitations during train traction and braking processes are taken to keep stand-up passengers safe and comfortable in vehicles. In most cases, the accelerations of train traction and braking are usually less than 1.2m/s2 [2]. The necessity of rail transit systems is derived from their ability to avoid the congestions on road network in urban areas with dense population. However, it does not mean people should ignore the explorations to pursue its economic efficiency. A rail transit system with higher train speeds will not only increase the construction investment, but also the operational cost of the system. For example, the energy consumption is an important cost in rail operations. In Guangzhou metro line 1, energy consumption occupies 34% of its total operational cost, only second to the man-power cost [1].

3. EFFECTS OF MAXIMUM SPEED ON OPERATIONS

The organization of rail transport and train formation is related with many factors, such as passenger demand distribution, station facilities, train control, signals system and so on. Among the factors, passenger demand distribution is the main aspect for vehicle selection and train formation. There is much demand along with the urban rail corridors. To meet the urban transport demand, urban rail transit systems provide sufficient carrying capacity. The rail line capacity is directly related with several parameters of trains. The model is mathematically described as below.

$$C_{line}=P_{car}*M_{train}*60/T_{headway} \tag{2}$$

Where C_{line} is the transport capability per hour on single direction; P_{car} is the number of passengers per vehicle; M_{train} is the number of vehicles per train, and $T_{headway}$ is the minimum train interval.

The energy consumption model of a train during its movement is described as below.

$$E = \sum_{i=0}^{n} e_i \cdot \Delta t \,, \quad i=0,1,..., n\text{-}1 \qquad (3)$$

where e_i is the energy consumption at each time step, and Δt is the time step. Here e_i is represented as:

$$e_i = f_i(t_i, v_i, C_i, X_i), \quad i=0,1,..., n\text{-}1$$
(4)

$$\sum t_i = T$$
(5)

where t_i is the running time of step *i, T* is the total running time of the section; C_i is the factor of manual control of train movement at step *i*, X_i is the distance factor at step and *n* is the number of time steps..

Because of the complexity in the process, there is not a suitable analytical model which can describe the different scenarios. Based on the simulator developed at earlier time, the authors extended its function to multi-train movement process [7]. The paper evaluates the impacts of train operation at different maximum speeds with the multi-train simulator.

4. CASE STUDIES

To specify the consequences of rail transit systems at different maximum speeds, the paper takes a 37km long rail line with 15 stations in Shanghai as example and develops an impact analysis on the indicators which are required to examine. The average distance between stations is 2.64km of the line. The train consists of 5 cars with total weight of 142 tons. Two simulation scenarios have been studied under the same operational environment at different design speeds.

Figure 2 gives the calculated speed profile of trains at maximum speed of 80km/h on the first two sections of the line. Figure 3 shows the speed profile of train with the speed limitation of 100km/h. In the figures, the solid line represents traction mode of the train, long dotted line represents the braking mode and dotted line represents coasting mode.

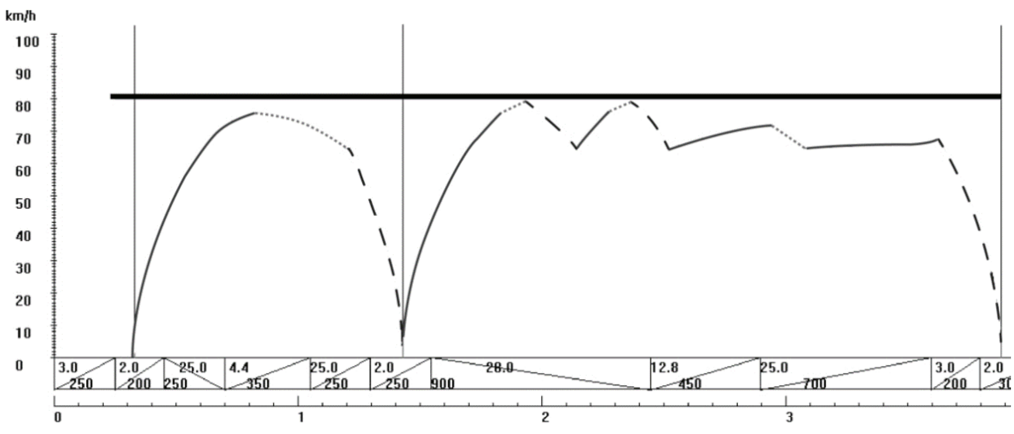

Figure 2 – Speed profile with the maximum speed of 80km/h

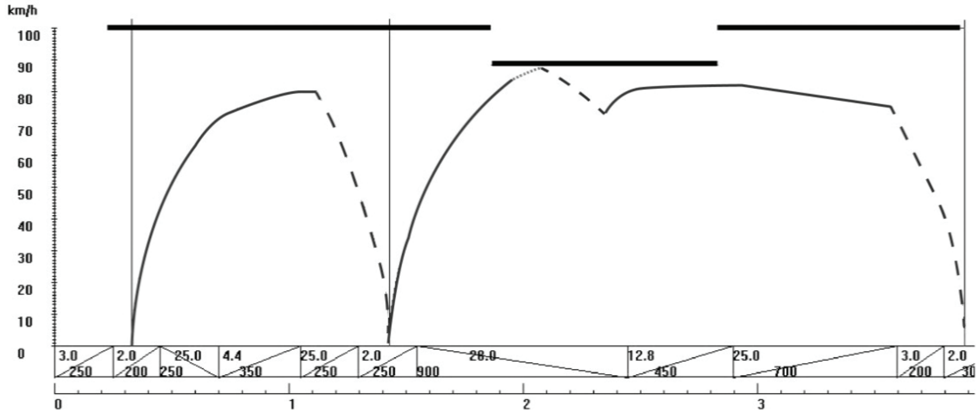

Figure 3 – Speed profile with the maximum speed of 100km/h

Two above figures state that the practical speed can only approach near 80km/h at the first short section even though the maximum speed has been set to 100km/h in the Figure 4. In the second longer section, there is a deep gradient which limits the train to get one possibly higher speed with the consideration of operational safety [2]. In the two cases, the coasting in speed profile at the maximum speed of 100km/h is much less than at 80km/h, which leads to more energy consumption.

Figure 4 gives the dotted line representing the simulation results based on the relationships between the station-station distance and average speed of trains. It bears noting that the shorter the station-station distance is, the lower the ratio of average speed and maximum speed of trains is.

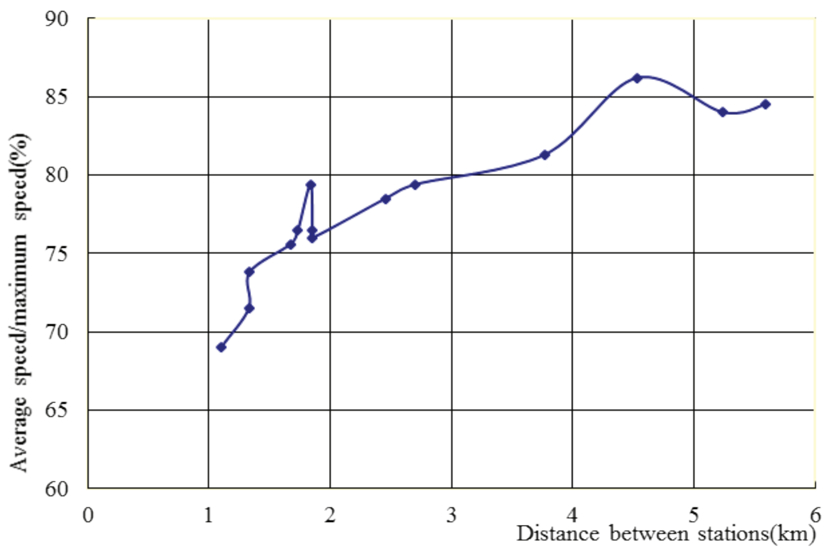

Figure 4 – Relationship between station-station distance and speed efficiency

Table 2 has listed the eastbound results of the distance between stations, the average speed and the travel time on each section of the line under three kinds of design speed. It is notable that the rate of average speed to design speed is 79.2 percent at 80km/h, but reduces 66.1 percent at 120km/h.

Table 2 – Train operational results under different design speed (Eastbound)

Section	Distance (m)	80km/h		100km/h		120km/h	
		Travel time (s)	Average speed (km/h)	Travel time (s)	Average speed (km/h)	Travel time (s)	Average speed (km/h)
1	1098	74.52	53.0	70.66	55.94	67.32	58.72
2	2455	142.05	62.2	132.09	66.91	127.78	69.17
3	2702	154.78	62.8	136.65	71.18	124.10	78.38
4	5587	301.16	66.8	245.32	81.99	213.61	94.16
5	4531	249.66	65.3	205.2	79.49	180.84	90.20
6	5241	283.83	66.5	230.65	81.80	202.15	93.33
7	3770	210.66	64.4	175.44	77.36	161.98	83.79
8	1837	107.43	61.6	96.68	68.40	90.85	72.79
9	1853	110.75	60.2	99.43	67.09	91.26	73.10
10	1334	83.71	57.4	78.4	61.26	74.39	64.56
11	1853	110.14	60.6	98.36	67.82	92.33	72.25
12	1734	103.07	60.6	93.62	66.68	88.30	70.70
13	1672	104.98	57.3	103.75	58.02	100.10	60.13
14	1328	84.33	56.7	77.23	61.90	75.95	62.95
Total	36995	2121.08	62.79	1843.47	72.25	1690.95	78.76

Table 3 summarizes the simulation results of train performance under three maximum speed scenarios of 80km/h, 100km/h and 120km/h. It is found that the traction rate, i.e. the percentage of traction time to total travel time, increases rapidly from 38.53% at 80km/h to 65.46% at 100km/h.

Table 3 – Train performance under different scenarios

Maximum design speed (km/h)	Average speed achieved (km/h)	Maximum speed achieved (km/h)	Energy consumption (kwh)	Traction rate (%)	Journey time (min)
80	62.79	79.32	224.57	38.53	38.7
100	72.25	99.2	275.57	65.46	34.0
120	78.76	119.18	383.08	67.40	31.5

To demonstrate above conclusions further, the paper develops another calculation based on a longer urban rail line of 22.64km in Beijing. The train on the line will adopt a through operation policy without any interim stop. Similar results are found that the proportion of the average speed to the maximum speed lies in the range of 85%~90%, while that of most urban rail lines lies in the range of 55%-65%. If the maximum speed is changed from 80km/h to 100km/h, 20% of the travel time will be saved. If the maximum speed is set to 120km/h, about 1/3 of the travel time will be saved. When the train travels at different design speeds of 80km/h, 100km/h and 120km/h, the proportion of energy consumption is about 100:115:145.

5. CONCLUSIONS

The cost for increasing maximum train speed depends on many factors. The first is the construction investments for higher quality standards on line geometry, tunnels, communications and signal system. The second is operational cost including energy consumption. The third is the cost for safety. It is worthwhile to note that the increase of maximum train speed in central urban areas is not so effective in improving level of service, but the augment it caused on operational cost varies very significantly.

From above studies, the conclusions are obtained as below.

(1) The average travel speed in the three scenarios with different maximum speeds will reach 62.79km/h, 72.25km/h and 78.76km/h respectively, which demonstrates the increase of the maximum train speed cannot get a linearly corresponding increase of the average train speed.

(2) The energy consumptions in the three scenarios with different maximum speeds are 224.57, 275.57 and 383.08kwh respectively, which shows the energy consumption increase more quickly than that of the maximum train speed.

Acknowledgement

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MAPPING OF NATURAL GAS SUPPLY CHAIN IN CROATIA AIMED AT CREATING A SIMULATION MODEL FOR SYSTEM IMBALANCE REMOVAL

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Abstract

With the growing importance of natural gas as the third most important fuel and fastest growing component of world primary energy consumption, its supply chains are becoming more complex in seeking ways for simultaneous optimization and further expansion. To gain clearer insight into situations and relations between members of the natural gas supply chain; to explore possibilities for optimization of its processes; to avoid multiplication of activities; and to prevent the occurrence of failures or catastrophes in the system, practitioners and scientist use supply chain mapping techniques. The paper aims to present existing types of supply chain maps, their benefits, limitations and methods for natural gas supply chain mapping through the case study method of mapping a Croatian natural gas supply chain. Mapping a natural gas supply chain serves the second objective of the paper, which is to develop a conceptual simulation model of physical and trading processes of natural gas in Croatia. Due to the mismatch of ordering (nominations) and withdrawal of gas made by balance groups, imbalances in the transportation system occur, which needs “balancing energy”. Consequently, balance groups that have a mismatch over the permitted limits are penalized. Exploring the reserves of transportation and distribution systems, the model aims to minimize or eliminate the inefficiencies resulting from the mismatch between the order (nomination) and the withdrawal of gas from the transportation system made by the balance groups under regulated market conditions. The initial version of the model was developed using Arena Simulation Software.

Keywords: *supply chain mapping, natural gas, simulation modelling*

1. INTRODUCTION

Natural gas is one of the cleanest and environmentally friendly fossil fuels and energy sources. From its extraction to its consumption natural gas usually doesn’t need to go through any transformation process [1]. World’s most relevant study [2] predicts 45 percent increase in global worldwide natural gas demand (the biggest rise of all energy resources) in period from 2015 to 2040. Natural gas features have contributed to the growth of its use around the world, therefore its cost effective, on-time, safe and widely spread transport and distribution are in main focus of natural gas supply chain members. Logistics and supply chain management plays crucial role in provision of natural gas – according to [3] transmission and distribution of natural gas to final consumers’ accounts for more than 30 percent of natural gas price. The importance of supply chain mapping in natural gas supply chains arises from need to gain clearer insight into situation and relations among members of natural gas supply chain at different levels, to explore possibilities for optimization of its processes, to avoid multiplication of activities and to prevent the occurrence of failures or even catastrophe in the system.

Republic of Croatia has high share of natural gas in overall primary energy production (27,1 %), as well as in overall primary energy consumption (21,9 %) [4]. Croatia produce around 50 % of its needs for natural gas and has one of smallest natural gas energy dependency in European Union (34,4 %) [5]. Its international part of natural gas supply chain is equally important as its domestic part since the Croatian natural gas supply chain is part of overall European natural gas supply chain, according to which the rules and directives are given by European Parliament and European Commission (Directive 2009/73/EC; EU Directive 2014/312/ EC).

The aim of this paper is twofold: *a)* to present existing types of supply chain maps, their benefits and ways of use for natural gas supply chain mapping through case study of mapping Croatian natural gas supply chain; *b)* based on the current supply chain analysis to identify the sources of the inefficiency of the process under regulated market conditions and to offer a conceptual simulation model that can serve to eliminate or minimize the inefficiencies resulting from the mismatch of the estimated demand and withdrawal of gas by the balance groups.

2. NATURAL GAS SUPPLY CHAIN MAPPING

Mapping is service, pervasive and supportive activity that is widely usable in all areas of supply chain management and by all members of the supply chain. Gardner and Cooper [6] define supply chain map as a *representation of the linkages and members of supply chain along with some information about the overall nature of the entire map*. Miyake et al [7] highlights how supply chain map result from the collection of different kinds of data and result in a holistic view that "no one person has ever caught in its entirety". Even most simple supply chain map, collaboratively developed, will lead to clearer understanding of each member's position and processes in supply chain, in turn can result in avoiding of work duplication in supply chain, higher motivation, better coordination, forecasting and replenishment efficacy, and increased chances for other supply chain process improvement [8]. To mitigate complexity, to clarify position and processes, and to ensure maximum possible optimization of natural gas supply chain, practitioners and scientist use mapping method in creating a "picture" of natural gas supply chain.

There are two main groups of supply chain maps [9]: relationship-based maps and activity-based maps.

Relationship-based maps are also called strategic supply chain maps [6], and they are used primarily to identify all supply chain members (or at least some that are key members), their position in supply chain and relations to each other, and ways how resources are flowing between them. These kinds of maps give more strategic and general overview of place and role of each member in the supply chain, and usually avoid highlighting of particular activities.

Activity-based maps are focused on a certain part or whole supply chain process describing some physical, information or value flow in it (flow can take place within or between companies). The main goal is to increase understanding of processes usually by increased process visibility. Lambert et al. [9] points some more popular activity-based supply chain maps: time-based process maps, pipeline inventory maps and extended value stream maps.

Recent study by Dujak [8] has generated that in 68 % of selected and analysed papers authors decided to use natural gas supply chain maps for giving clearer and understandable situation, relations or process flow in natural gas supply chain. The most often used type of supply chain maps for mapping natural gas supply chain are relationship based maps (in 83 % of papers), based on strategically approach to primarily supply chain members and flows. The reason behind is a fact that relationship based maps are suitable for presenting more static environment what is most often case in natural gas supply chain papers. Time based supply chain maps that usually appear in form of process maps are used in only 33 % of analysed papers. According to the main topic and accents of paper's research, supply chain maps equally represent the whole natural gas supply chain as well as only parts of natural gas supply chain. Geographically representative maps are rare in papers dealing with natural gas supply chain. Furtherly, natural gas supply chain maps mostly don't use focal approach (are not drawn from the perspective of a supply chain member that is in focus) and don't use cycle view (as there are almost no return flows in natural gas supply chain). This is the reason why other models (like simulations and system dynamics) are also used to present the dynamics of the system or its part.

3. CROATIAN NATURAL GAS SUPPLY CHAIN

3.1. Integrated map of Croatian natural gas supply chain

Natural gas supply chain in the Republic of Croatia is a complex system that is built and operates on the given technological bases and in strictly defined rules and legal conditions. It can be seen as a multilayer dynamic structure in which physical flows and infrastructure, supply and final consumption as well as balancing are divided for rational utilization of all resources and capacities as well as fulfilling demand of all categories of consumers. Integrated map of Croatian natural gas supply chain is given in Figure 1.

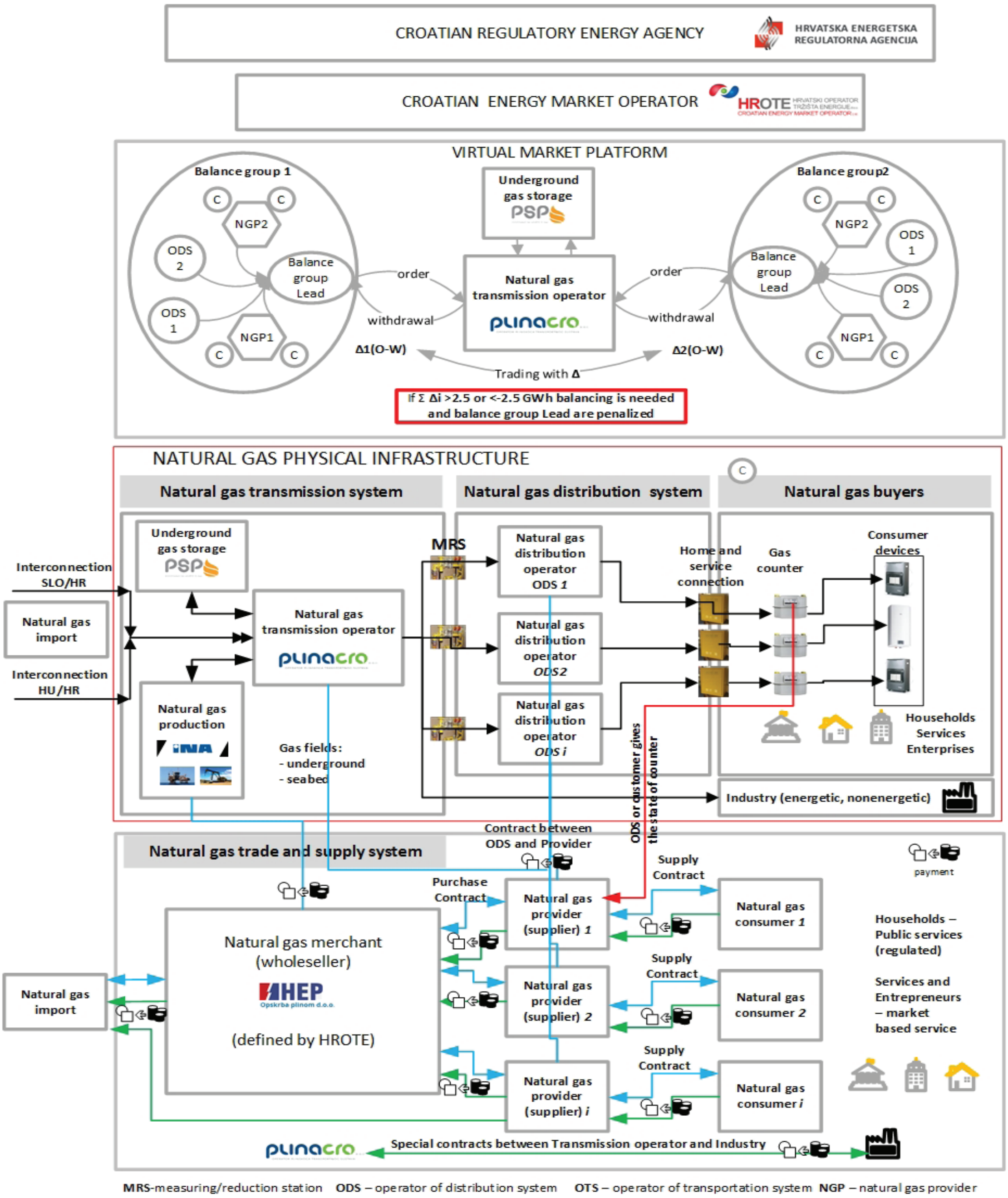

Figure 1 – Integrated map of Croatian natural gas supply chain (adapted and extended from http://www.gpz-opskrba.hr/korisne-informacije/shema-plinskog-sustava-i-trzista-plina-u-rh-55/55)

Physical infrastructure and material flows

Production

"Natural gas is produced from 16 on-shore and 10 off-shore gas fields meeting 70.7 percent of total domestic demand. However, when gas produced in the Adriatic that actually belongs to Croatia is included in calculation, domestic gas amounts to 56.1 percent of Croatian total gas demand. More than half of total gas production has been gained from the Adriatic Sea" [10; 133]. Overall production was 1.780,5 mil m^3, import was 1.060,1 mil. m^3, export was 367,4 mil m^3 and stock change was 56 mil m^3.

Gas Transmission

"Natural gas transmission is a regulated energy activity performed as a public service and represents the primary activity of the company PLINACRO Ltd, which is the owner and the operator of the gas transmission system. In 2015, 26.371 million kWh of natural gas were transported, of which 22 542 million kWh from the entry points to the exit measuring-reduction stations, and 3 829 million kWh to the underground gas storage Okoli. At the system level, maximum gas transmission achieved in 2015 was 113 million kWh/day.

PLINACRO manages a total of 2 694 km of pipelines of which 2 410 km was engaged in gas transmission in 2015. Gas is delivered from the transmission system through 164 connections at 157 exit measuring-reduction stations. 38 connections are in function of gas delivery points for industrial consumers on the transmission system, whereas 126 connections are used for gas delivery to gas distribution systems" [10; 134].

Storage

"The underground gas storage Okoli is operated by the company Podzemno skladište plina, Ltd. which is owned by the transmission system operator PLINACRO Ltd. and that generated its revenue through the provision of natural gas storage at regulated conditions defined by the Croatian Energy Regulatory Agency. Technical conditions, operation, management, development and maintenance of the storage system, connection with other parts of gas system, the rights and duties of operators and users of the gas storage system, contracting procedure as well as connecting with other parts of the gas system are regulated by the Rules of the gas storage system usage (UPR-175 - 1/2014 published on 29th December 2014), which is brought after a public hearing with the consent of the Croatian Energy Regulatory Agency. Maximum withdrawal capacity is 240 000 m^3/h, and maximum injection capacity is 160 000 m^3/h. During 2015 a total of 236 million m^3 of gas was injected into gas storage while about 290.8 million m^3 of gas were withdrawn during the withdrawal cycle" [10; 137].

Distribution

There were 35 companies for natural gas distribution in the Republic of Croatia in 2015. Total gas distribution network in Croatia is 17 627 km long. During the 2015 1.081.786 mil m3 gas was distributed [10; 138].

Consumption

Overall consumption of natural gas in 2015 was 2.519,2 mil m^3 of which Energy sector own use was 129,0 mil m^3, energy transformation (thermo power plant, public cogeneration plants, heating plants, industrial heating plants, refineries, gas works and NGL plants) 881,6 mil m^3, Non energy use 495,6 mil m^3 and Final energy consumption 981,3 mil m^3 (Industry 211,1, Transport 4,0, households 540,0, services 204,8 and agriculture 24,1 mil m^3) [10; 140].

Supply

"The license for gas supply activities in Croatia in 2015 obtained 56 energy companies, out of which 46 were actively engaged in gas supply activities. Based on the gas Market Law ("Official Gazette" no. 28/2013 and 14/2014) Croatian Energy Regulatory Agency has issued General terms of gas supply ("Official Gazette" No. 158/2013). In early 2014, HEP (Croatian Electric Power Industry) was determined as the supplier in the wholesale gas market by the Decision on determining the supplier in the wholesale gas market ("Official Gazette" No. 29/2014). HEP is obligated to sell gas to suppliers in the public service for the needs of household customers under regulated conditions and provide a reliable and secure supply, including gas import to Croatia. [10; 142].

3.2. Development of simulation model

Starting from the integrated natural gas supply chain map and respecting the rules and legal frameworks of natural gas system, a conceptual solution of simulation model was proposed with the aim of exploring the possibility of eliminating system inefficiencies, i.e. exploring the possibility of adapting the system to balance disorders arising from the mismatch between gas nomination and withdrawal from the transmission system. The key problem with the nominations is to find the most reliable assessment models for the daily and even hourly consumption. The withdrawal of gas from the transmission system of particular balance group should be aligned with the order (nomination) placed to the transmission system. However, as errors in nominations (orders) always occur, the withdrawal of gas from the transmission system (and storage) is not consistent with the nominations, which causes imbalances in the transmission system. Due to the balancing transmission system with so called "balancing energy", balance group is being penalized. Although the balance groups have the ability to trade the surpluses and shortfalls on the trading platform, our goal is to explore what adaptive possibilities are available to the distribution systems for adaptation and to take part of the imbalance in accordance with their capacities and technological capabilities. Initial model is developed by using Arena Simulation Software. Graphical representation of model is given in Figure 2.

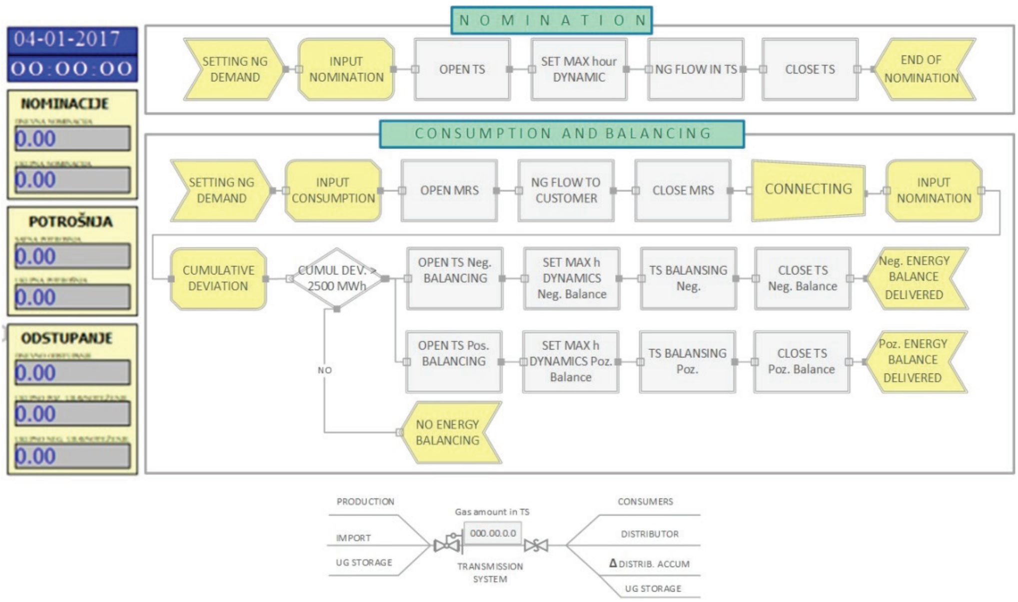

Figure 2 – Graphical representation of simulation model

Key variables of model are consumption per hour and daily nominated amounts of gas. The model works as follows: In the NOMINATION part starting point is setting gas demand for gas day. Based on actual data, the Input Analyser determines the equation that simulates the nomination. It comes to the "Open TS" module, which opens the gas in the TS. With the "Set nominal dynamics of the nomination" module, the total nomination is divided by 24, giving equal hourly nomination. The "Gas flow in TS" module is released into the transport system and the gas inlet valve closes after 24 hours.

In the part CONSUMPTION AND BALANCING – The "Setting NG demand" module simulates the distribution system consumption. This part of the process starts by creating gas consumption for each hour. The MRS valve opens and the gas is ejected from the transmission system to the distribution. The MRS valve is then closed. The "Connecting" module is waiting to be collected for all 24 hours. The module "Cumulative daily deviation" calculates the difference between daily nomination and daily consumption. When this cumulative deviation exceeds +/- 2,500,000 kWh then balancing the transportation system is done (withdrawing from or injecting to gas storage). If the deviation is > 2,500,000 kWh, negative balancing is made (because the nomination is higher than the consumption), and the gas withdrawal from the TS is made. If the deviation is less than -2,500,000 kWh, it is positive balancing, so the gas is injected to the TS.

Model was initially tested on the data publicly available on the Transportation system web site. We have the data of one month consumption on daily and hourly basis and nomination made of all balance groups on daily basis. Hourly consumption during the each gas day (according to input analyser) was distributed in accordance with Erlang distribution. Nomination (e.g. planned consumption) was equally distributed on every hour. Differences between consumption and nomination were calculated and cumulate on daily basis. We made 30 iteration for 24 hours. Cumulative monthly consumption error was 10.32% and cumulative monthly nomination error was 0.34%. Our initial model is made on assumption that 1 MRS exists as well as one balance group. Our future model will be enhanced including additional variables like gas pressure and temperature for altering distribution system capacity and also combination of more balance group associated to the distribution system. Data will be collected from 2 year historical data of the variables available on one of the biggest Croatian distribution system and all balance groups associated to the distribution system.

4. CONCLUSION

For a full understanding of the natural gas supply chain, it is useful to use different types of maps that reveal the participants, their roles, activities, processes, material, information and value flows as well as possible inefficiencies and risks that might occur in the supply chain. However, the maps generally have a static character and for the dynamics of the entire supply chain it is necessary to build additional models that will reveal the behaviour of the system and its dynamics relevant to the specific aspects of the system's observation. The integrative model of the natural gas supply chain with the consideration of rules, legal and technological frameworks in which the supply chain operates, is the basis for the development of a dynamic simulation model that seeks to solve some inefficiencies in the system. Since the parts of the gas market are regulated, as the key measures to ensure business process efficiency available to supply chain participants joined in balance group are well defined forecasting and demand planning as well as technological solutions for adaptation allowing consistency of supply and natural gas consumption. Modern prediction models of natural gas consumption, based on neural networks and machine learning methods, have shown promising results for solving the first problem [11] as well as a combination of different model (mathematical, multiple linear regression, dynamic model adaptation) [12]. Proposed simulation model will try to resolve the problem of adaptation of distribution system to compensate potential disturbances and thus avoid penalizing due mismatch of order and withdrawal. Model is in its testing phase and should be developed further on the real data from the two balance groups.

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WEB INFORMATION SYSTEM FOR SUSTAINABILITY OPTIMIZATION OF PRODUCTION NETWORKS

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Abstract

Industry 4.0 brought the introduction of Information and Communication Technology (ICT) and Internet of Things (IoT) into production systems. It led to the definition of Cyber-Physical Production Systems that enabled the definition of new production network concepts like Cyber-Physical Production Networks or, simply, Social Manufacturing. In this research, focus has been put on selection of the partners (enterprises) for the manufacturing process based on a multi-criteria approach that focuses on the three P's of sustainable development: People (society), Planet (environment), and Profit (economy). A specialized algorithm with a priori approach to multi-objective optimization has been applied on the Partner Selection Problem instance with 7 criteria (objectives). Furthermore, a concept of a Web information system for practical application of sustainable management of production networks is also presented.

Keywords: *information systems in logistics, operations management and scheduling, global logistics*

1. INTRODUCTION

Despite all the research through more than 20 years, non-hierarchical production networks [1] consisting of autonomous enterprises are still far away from the practical application. In the practice, production networks are only research and development projects or living labs. Although some global corporations are using their own production networks across continents [2], it is not at all similar concept to the original idea of non-hierarchical production networks [3]. Main difference between the global supply chains and production networks is in the fact that in supply chain an enterprise is manufacturer or distributor of some part, product, raw material, or similar. But, in production networks, it is not about parts and products, it is about competences sharing, i.e. sharing of processes, technologies and knowledge in all phases of production process: marketing, product development, production planning, manufacturing, assembly, logistics, and quality/services [1]. So production networks represent more complex system to manage and theirs long-term sustainability of collaborations is, often, doubtful. Furthermore, elements of both, multi-agent system and holonic system, can be identified in the phenomenology of production networks [3].

However, with Industry 4.0 and introduction of Information and Communication Technology (ICT) and Internet of Things (IoT) into production systems [4], i.e. with definition of Cyber-Physical Production System a new concepts have been described in the literature, like Cyber-Physical Production Network (CPPN) [5], Self-optimizing production networks [6], Agent-based production coordination [7], Cyber Manufacturing Systems [8], and Network of Socio-Cyber-Physical System (SCPS) [9]. Furthermore, for production networks that are focused only on manufacturing and assembly, new ICT/IoT based concept is simply called: Social Manufacturing [10].

In this research, a focus is on selection of partners [11] (enterprises) for manufacturing processes [12], like in Social Manufacturing. Main aim of this research is sustainability optimization which occurs in creation phase of virtual enterprise. A generic term 'virtual enterprise' is often used in production networks representing a collaboration among enterprises. Creation of virtual enterprise is one phase of virtual enterprise lifecycle [13] which is in correlation with product lifecycle. Since virtual enterprise lifecycle needs to be managed somehow, it is clear that management of production networks is not an easy task. Main reason is that the organization of production network must remain non-hierarchical. Therefore, a concept of Web information system for sustainable management of production networks is also presented in this research.

2. METHODS

2.1. Web information system for production network management

In this research, a Web information system for production network management has been designed as a Smart Collaborative Platform 'VENTIS'. The concept of 'VENTIS' platform is the concept of the decision support systems, with data, models and user interface (dialogue) as three main elements. All these elements are integrated into 'VENTIS', as it is schematically presented in Figure 1.

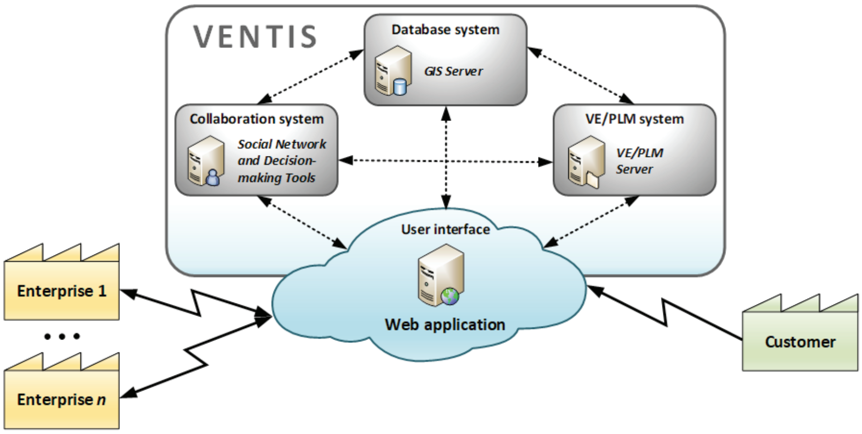

Figure 1 – Schematic design of Smart Collaborative Platform 'VENTIS' and its main elements

The only difference between VENTIS and classic decision support systems is that models in VENTIS are divided into two groups: Social network and Decision-making tools, and Virtual Enterprise (VE) and Product Lifecycle Management (PLM). In this paper, a Decision making-tool for optimization of partner selection, in order to increase sustainability of virtual enterprise, is presented.

2.2. HUMANT algorithm and the Partner Selection Problem

Partner Selection Problem (PSP) is already known optimization problem in production networks [11] or agile manufacturing [12]. Since the PSP is usually multi-objective optimization problem, it requires an algorithm that can solve multi-objective problems. HUMANT (HUManoid ANT) algorithm [14] uses *a priori* approach to multi-objective optimization by combining the Ant Colony Optimization (ACO) and multi-criteria decision-making PROMETHEE method [15]. The PROMETHEE method is implemented into three main ACO equations. For evaluation and comparison of nodes of the graph following equation is used [14]:

$$p_{ij} = \frac{[\tau_{ij}(t)]^{\alpha} \cdot [\Phi'_{ij}]^{\beta}}{\sum_{k=1}^{n}[\tau_{ik}(t)]^{\alpha} \cdot [\Phi'_{ik}]^{\beta}} \tag{1}$$

where p_{ij} represents the probability that ant will move from node i to node j, τ is the pheromone level on edge connecting nodes i and j, α and β are parameters of the ACO algorithm, and Φ'_{ij} represents the modified PROMETHEE II score for edge connecting nodes i and j. This score calculated using following equation [14]:

$$\Phi'_{ij} = \frac{\frac{1}{n-1}\sum_{k=1}^{n}(\Pi(x_{ij},x_{ik})+(1-\Pi(x_{ik},x_{ij})))}{2}$$

(2)

where Π represents aggregated preference index defined for each pair of nodes. This is a little bit modified PROMETHEE II score to produce the output in [0, 1] interval instead of [-1, 1] interval. The equation (2) can also be used to compare two different solutions of the problem in order to find the optimal one. However, pheromone update can be a problem, since PROMETHEE method is not based on utility functions, therefore each solution is compared with ideal solution of the problem, which is additional parameter of algorithm [14]:

$$\Delta\tau_{ij} = 2(\Phi'(x)) = 2\left(\frac{\Pi(x,s^{id})+(1-\Pi(s^{id},x))}{2}\right)$$

(3)

where x is the solution and s_{id} is the known optimal solution (for previously solved optimization problems). If the optimal solution is unknown, then the ideal solution is used [16].

HUMANT algorithm demonstrated significant performance in solving Partner Selection Problem [16]. Therefore, HUMANT algorithm is used in this paper to solve PSP with 7 criteria (objectives).

3. RESULTS

Sustainability is generally seen through three P's: People (society), Planet (environment), and Profit (economy). Therefore, Partner Selection Problem with these 3 groups of criteria (objectives) is used in this research. In order to demonstrate sustainability optimization, a production network consisting of 6 enterprises has been created. Enterprises are geographically dispersed in 6 different European cities. In total, 7 criteria are used, but only 6 of them have known evaluations (Table 1). The seventh criterion is transport, but its evaluation is unknown before optimization, so it varies depending on the selected partners (enterprises). Evaluation of transport is made using Euclidean distance (Table 2). Criteria information and parameters for PROMETHEE method are given in Table 3. Criteria evaluations for the cities are criteria evaluations for the countries to which the particular city belong, so they are not precise. These data have been collected from Eurostat database [17]. Some of the data are for 2017, and some of the data are for 2015 or 2016.

The manufacturing process with potential partner (enterprise) for each technological step (sub-process) is presented in Table 4. It is the PSP that needs to be solved by using HUMANT algorithm, and taking into account all input data (Table 1, 2 and 3).

Table 1 – Evaluations of enterprises (partners) on economic, environmental and social criteria

Enterprise (City)	*Economic criteria*		*Environmental criteria*		*Social criteria*	
	C1 Labour cost (€/h)	*C2 Electricity cost (€/kWh)*	*C3 CO_2 emission (t/MWh)*	*C4 Manufacturing waste (kg/person)*	*C5 Unemployment rate (%)*	*C6 GDP* per capita (k€)*
Barcelona	23.30	0.113	0.440	318.65	16.70	90
Genoa	27.80	0.160	0.483	437.04	11.10	96
Hamburg	38.80	0.149	0.624	756.03	3.60	124
Manchester	26.00	0.152	0.543	124.32	4.20	108
Nantes	38.30	0.095	0.056	329.17	9.70	107
Vienna	36.00	0.105	0.209	634.48	5.60	128

* *GDP = Gross Domestic Product*

Table 2 – Euclidean distance matrix between cities (enterprises)

	Barcelona	**Genoa**	**Hamburg**	**Manchester**	**Nantes**	**Vienna**
Barcelona	0	646	1475	1386	714	1351
Genoa	646	0	1021	1297	872	710
Hamburg	1475	1021	0	809	1079	744
Manchester	1386	1297	809	0	699	1429
Nantes	714	872	1079	699	0	1344
Vienna	1351	710	744	1429	1344	0

Table 3 – Criteria information and parameters for PROMETHEE method

Criteria ID	*Criteria names (units)*	*Criteria objectives*	*Aggregation type*	*Preference function*	*Indifference threshold*	*Preference threshold*
C0	**Transport** (km)	Minimize	Sum	Linear	0	4425.0
C1	**Labour cost** (€/h)	Minimize	Mean	Linear	0	15.5
C2	**Electricity cost** (€/kWh)	Minimize	Mean	Linear	0	0.1
C3	**CO_2 emission** (t/MWh)	Minimize	Mean	Linear	0	0.6
C4	**Manufacturing waste** (kg/person)	Minimize	Mean	Linear	0	631.7
C5	**Unemployment rate** (%)	Maximize	Mean	Linear	0	13.1
C6	**GDP per capita** (k€)	Minimize	Mean	Linear	0	38.0

Table 4 – Steps of manufacturing process with potential partner (enterprise) for each step

	Casting	*Machining*	*Annealing*	*Polishing*
Enterprise (ID)	**Barcelona (1)** **Genoa (2)** **Hamburg (3)**	**Manchester (4)** **Genoa (2)** **Hamburg (3)**	**Manchester (4)** **Nantes (5)** **Vienna (6)**	**Barcelona (1)** **Nantes (5)** **Vienna (6)**

Since HUMANT algorithm, i.e. PROMETHEE method, allows setting the values for criteria weights, a set of 7 scenarios has been made, where each scenario represents different set of criteria weights (Table 5).

Table 5 – Scenario set for partner selection problem

Scenario	*Economic criteria*			*Environmental criteria*		*Social criteria*	
	W_{C0}	W_{C1}	W_{C2}	W_{C3}	W_{C4}	W_{C5}	W_{C6}
Scenario 1	0.114	0.113	0.113	0.165	0.165	0.165	0.165
		Σ = **0.34**		Σ = **0.33**		Σ = **0.33**	
Scenario 2	0.240	0.230	0.230	0.050	0.050	0.100	0.100
		Σ = **0.70**		Σ = **0.10**		Σ = **0.20**	
Scenario 3	0.240	0.230	0.230	0.100	0.100	0.050	0.050
		Σ = **0.70**		Σ = **0.20**		Σ = **0.10**	
Scenario 4	0.067	0.067	0.066	0.050	0.050	0.350	0.350
		Σ = **0.20**		Σ = **0.10**		Σ = **0.70**	
Scenario 5	0.067	0.067	0.066	0.350	0.350	0.050	0.050
		Σ = **0.20**		Σ = **0.70**		Σ = **0.10**	
Scenario 6	0.034	0.033	0.033	0.100	0.100	0.350	0.350
		Σ = **0.10**		Σ = **0.20**		Σ = **0.70**	
Scenario 7	0.034	0.033	0.033	0.350	0.350	0.100	0.100
		Σ = **0.10**		Σ = **0.70**		Σ = **0.20**	

HUMANT algorithm has been used to solve proposed PSP based on 7 different scenarios. Algorithm was found 7 solutions, one for each scenario. However, some of the solutions, found for different scenarios, are identical. At the end, there are 3 different combinations of partners (3 virtual enterprises) for these 7 scenarios. They are presented in Table 6 and Figure 2.

Table 6 – Scenario results with values for each criterion

Criteria ID	*Criteria names (units)*	*Criteria objectives*	*Aggregation type*	*Scenario results* Scenario 1, 2, 4, 6	Scenario 3	Scenario 5, 7
C0	**Transport** (km)	Minimize	Sum	2232	1518	2085
C1	**Labour cost** (€/h)	Minimize	Mean	28.18	31.93	31.48
C2	**Electricity cost** (€/kWh)	Minimize	Mean	0.12	0.12	0.11
C3	**CO_2 emission** (t/MWh)	Minimize	Mean	0.35	0.26	0.27
C4	**Manufacturing waste** (kg/person)	Minimize	Mean	350.88	353.51	275.33
C5	**Unemployment rate** (%)	Maximize	Mean	13.55	11.80	10.08
C6	**GDP per capita** (k€)	Minimize	Mean	95.75	100.00	103.00

A visual scenario comparison is given in Figure 3. It is important to note that six criteria have minimization as an objective, and only one criterion (C5 – Unemployment rate) has maximization as an objective. Because, that criteria belongs to the group of social criteria, and social criteria are used as social sensibility toward areas (countries) with higher unemployment (maximization as an objective) and lower GDP per capita (minimization as an objective).

It is also important to note that each criterion has its own aggregation type. In this PSP instance, six criteria have ‘mean’ as aggregation type, which means that a mean value will be used to evaluate (aggregate) total value for that criterion. A mean value is calculated, since the PSP instance has four technological steps for which four partners need to be selected. So, it is a mean value of criterion evaluations for selected partners. For transport, a sum is used as an aggregation value. It means that Euclidean distance between selected partners is summed taking into account transportation steps defined by the manufacturing process.

At the end, it is very important to highlight that in the term of multi-criteria decision-making, three solutions found by the algorithm are not three different optimal solutions, but three optimal compromises. Namely, in multi-criteria decision-making it is always selection of the best compromise, because optimal solution would mean that it is the solution better than all others on each criterion, or better on at least one criterion and equal on all other criteria. In the reality, such a kind of optimal solution usually does not exist. Therefore, in sustainability optimization, it is always search for the best compromise, like in case of production networks.

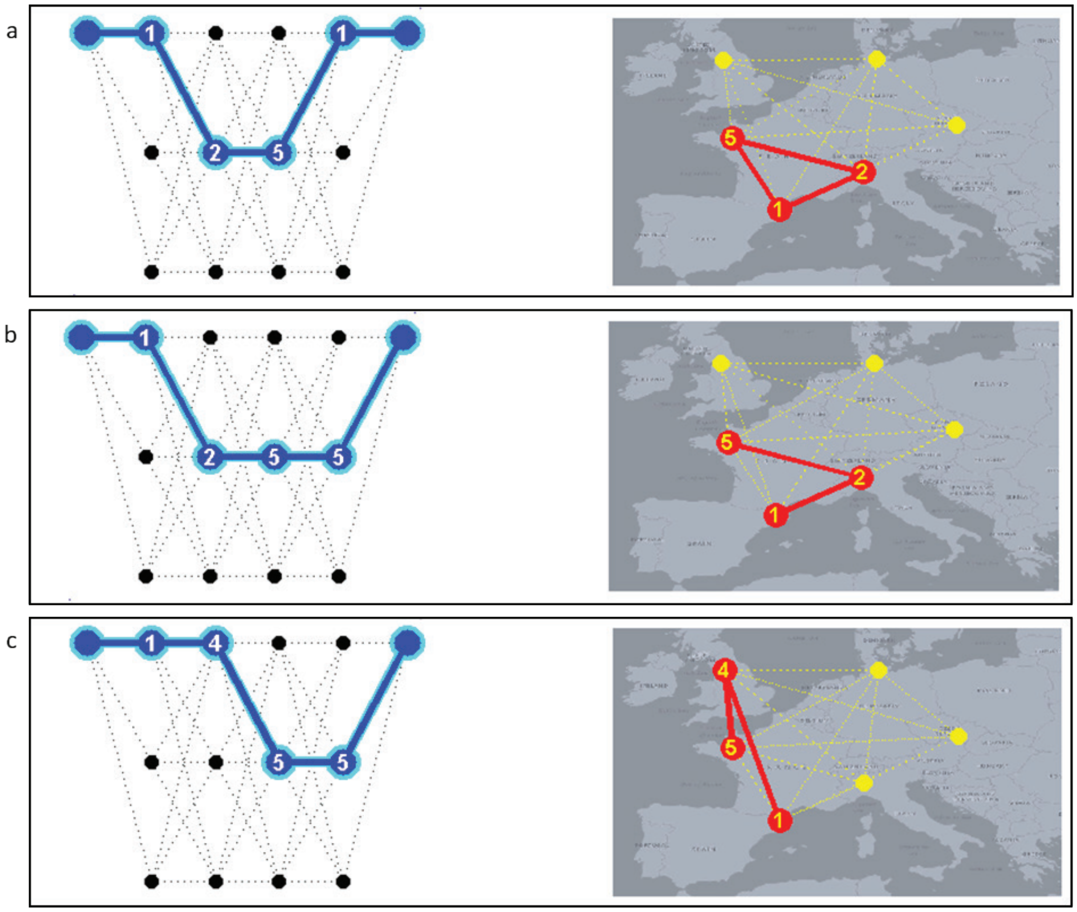

Figure 2 – (a) Optimum with map representation for Scenario 1, 2, 4 and 6; (b) Optimum with map representation for Scenario 3; (c) Optimum with map representation for Scenario 5 and 7

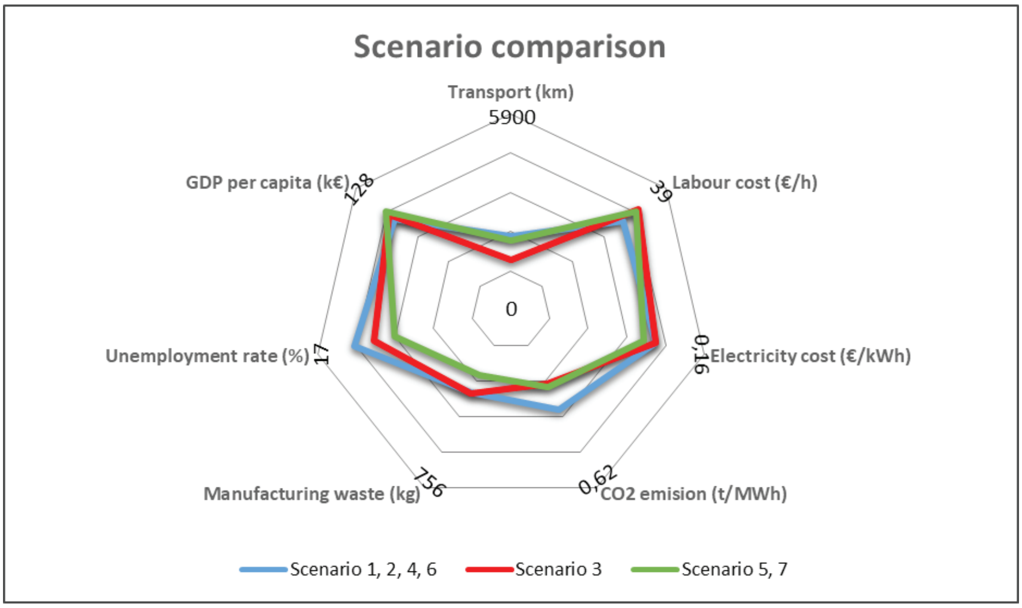

Figure 3 – Scenario comparison on radar chart

4. CONCLUSION

Aim of this research was to demonstrate that sustainability of production network could be maximized by selecting optimal combination of partners (enterprises) based on multi-criteria approach which focuses on the three P's of the sustainable development: People (society), Planet (environment), and Profit (economy).

An instance of Partner Selection Problem, consisting of six enterprises (partners), manufacturing process with four steps and seven criteria (objectives), has been successfully solved using the HUMANT algorithm. Seven criteria were grouped into three groups that represent sustainability: economic criteria, environmental criteria, and social criteria. Furthermore, since the HUMANT algorithm uses PROMETHEE method for multi-criteria decision-making, seven different scenarios were defined representing seven different sets of criteria weights. Some scenarios resulted with same solution, so, at the end, three solutions were found for seven scenarios. These solutions have elements of a Pareto set of optimal solutions, but from the perspective of multi-criteria decision-making these solutions are the best compromises.

It is clear that approach presented in this research have a potential for further research and development of Web information system for the sustainable management of production networks. The main aim of the further research should be focused on analysis of stability intervals for criteria weights to avoid rank reversal problems and to make the whole decision-making process more transparent.

5. ACKNOWLEDGEMENTS

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A FRAMEWORK FOR INNOVATION CAPABILITY PERFORMANCE ASSESSMENT IN BRAZILIAN LOW-TECH SMALL BUSINESS

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Abstract

This article presents a proposal for a framework for the evaluation of innovation performance resulting from innovation capability of Brazilian low-tech small companies. It was built as a reference model and is based on three increasing levels of granularity: performance perspectives, performance parameters and evaluation parameters. This framework has several potential applications, generating benefits from the provision of conceptual guidelines that can increase the competitiveness and innovation performance of small Brazilian companies through differentiations and innovations based on management mechanisms that are independent of formal research and development.

Keywords: *operations management, economic aspects of logistics, customer service*

1. INTRODUCTION

The attention dedicated by the academic literature to small businesses has grown in recent years. Studies on this class of companies have increasingly integrated the world academic production [1]. These companies hold a significant importance for national economies, and considering the Brazilian context small companies form the basis of society and economy in times of transformation [2].

Currently, there is a broad consensus that, since small companies have distinctive peculiarities to companies of different sizes, the study of management of these enterprises justifies, by itself, the need to construct a specific theory on this subject [3]. In terms of research and economic analysis in Brazil, the literature has traditionally approached small businesses with a social bias, valuing their importance for the maintenance of the employability of a large portion of the economically active population [4].

Considering an economic perspective, this class of enterprises has shown a growing participation in the Brazilian economy, but still significantly below the medium and large companies. For example, [5] emphasized the importance of understanding innovation capability in low-tech companies operating in the oil and gas sector in Brazil as a way to overcome the logistical challenges of exploration and production operations in ultra-deep waters in the country. However, traditionally, the academic literature still holds the idea that Brazilian small companies have low innovation capability. This is due to two reasons.

Firstly, because a significant portion of Brazilian small companies operates in commerce, commonly considered as traditional sector, conservative or not innovative [6]. Second, because a less significant portion of these firms operates in the industry, which is considered to be a more technologically dynamic sector, especially if the classical view that innovation is pushed by technology and research and development (R&D) as its central engine is adopted [7].

Regarding studies on innovation in Brazilian small companies, two limitations can be observed. The first concerns the reduced number of studies on this topic in this particular class of companies [4, 8, 9]. This scenario implies that, in order to obtain reliable information, Brazilian researchers in this particular field mainly need to complement their studies with international material. However, the internal and external contexts can be quite different and heterogeneous between companies from different countries [10], especially in terms of their logistics strategies [11].

The second limitation refers to the approach adopted in Brazilian studies on innovation in small companies. A significant part of these studies tends to focus on companies inserted in environments with greater technological dynamism, usually referred to as 'technology-based small companies' [9, 12]. These companies, in spite of their size, are generally characterized by the interface with new scientific and technological developments, as well as the proximity to academic research environments and technological development centers [13].

This article presents a proposal for a framework to the evaluation of innovation performance resulting from innovation capability of Brazilian low-tech small companies. The model was constructed based on an adaptation of a methodology to construct reference models [14], and is based on three increasing levels of granularity that are: performance perspectives, performance parameters and evaluation parameters. The model presents a customized structure to the Brazilian reality, aligned with [4, 9, 12], and can serve as an important conceptual basis for studies on small business in Brazil, particularly from the perspective of operations management, economic aspects of logistics and customer service. It is also evaluated that, from simple conceptual adaptations, the model can be used in other countries.

2. THEORETICAL BACKGROUND

In Brazil, current legislation classifies the size of companies using as a criterion the gross income earned in a year. This classification indicates that a small company obtained a gross revenue in a year between R$ 360,000 and up to R$ 3,600,000, (or, approximately, between US$ 110,700 and up to US$ 1,107,000) [15]. Despite the heterogeneity found in Brazilian small companies [16], the literature identifies some essential characteristics shared by these enterprises. The Brazilian Institute of Geography and Statistics (IBGE), for example, states that some of the main characteristics of small Brazilian companies are: low capital intensity, high rates of birth and mortality, centralized decision power, low investment in technological innovation, difficulty to access financial capital and a relationship of subordination to large companies [4].

Innovation capability consists of factors that affect an organization's potential to manage innovation, divided into three aspects: innovation potential, which reflects the factors that affect the current state of innovation capability of the organization; innovation processes, which help the organization to utilize its innovation potential and thus enable innovations; and, finally, innovation outcomes, which are the resulting outputs, such as innovative goods, services and processes [17]. Complementarily, innovation capability in organizations must be understood from a maturity point of view, considering a set of organizational dimensions, which encompass inputs and processes, and outcomes, which encompass outputs and its effects [18].

There is no consensus in the literature on the dynamics of innovation capability in the specific context of small firms. If, on one hand, these companies are perceived as more prone to innovate because of high flexibility, greater adaptability and speed in implementing organizational changes, on the other hand they are recognized as less able to identify opportunities and trends, to establish networks of partnerships, to collect external information and to measure the results obtained in the market, among several others [19].

Innovation is possibly independent of company size and sector [20]. However, small businesses tend to innovate incrementally, even though they are capable of producing a variety of innovative outputs, such as new products (goods and services), processes and production methods [21]. Therefore, the evaluation of innovation in small enterprises should focus more on management practices than on R&D [10]. This approach has found resonance in other studies. Regarding small firms, current literature points out that innovations are not necessarily formal R&D results but rather results from daily business development, customer collaboration or process optimization, including logistical processes [22].

Among the informal research and development activities carried out by small business are experimentation, learning, evaluation and adaptation of existing technologies. Also, non-technological forms of innovation contribute to improve the performance of small businesses [10]. In terms of measurement of effects, an evaluation of the innovation performance of small enterprises can be made in two fundamental perspectives:

financial and non-financial [23]. In a more complex view, operational, customer satisfaction, human and financial resources perspectives can be used [17].

3. METHOD

The method used to develop the model was a simplification of a set of guidelines for the construction of reference models based on empirical evidence [14]. The model was conceived from a top-down structure, with three levels of granularity, from the most general to the most specific level, in the form of performance perspectives, performance parameters and evaluation parameters. Each of these levels was made compatible with the characteristics of Brazilian low-tech small companies, in order to provide a model that is adherent to reality. An overview of the model construction is presented in Figure 1.

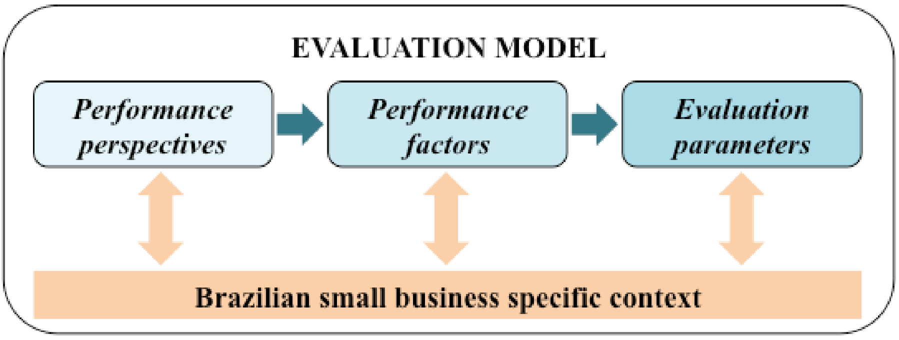

Figure 1 – Model construction overview

In terms of the implementation of the method, [17] was defined as the primary conceptual basis for innovation performance perspectives in small enterprises. Initially, a literature review of the performance factors and evaluation parameters linked to these perspectives was carried out. After analysis and refinement of the results, a set of key documents was selected for the model construction [24, 25, 26, 27, 28]. The factors and parameters were selected, classified, and then matched ontologically in two perspectives, horizontal (between factors and parameters) and vertical (factors amongst themselves and parameters amongst themselves). Then, this set of factors and parameters was aligned with the performance perspectives, constituting a "meta-model" of evaluation. Finally, this "meta-model" was made compatible with the main characteristics (based on empirical evidence) of low-tech Brazilian small companies [4, 9, 12].

Performance perspectives were defined as operational, customer satisfaction, human resources, and financial performance [17]. Associated with these perspectives, a set of performance factors primarily extracted from [24] and complemented by [25, 26, 27, 28]. Linked to the performance factors is a set of evaluation parameters. These parameters of evaluation derive fundamentally from [23] and can be used as support mechanisms for the construction of instruments for evaluating innovation performance of small Brazilian low-tech companies. Based on this initial model, reconciliation between the model and the reality of Brazilian companies was made, using the guidelines of [4, 9, 12], as shown in Table 1.

4. RESULTS

Considering the conceptual structure presented, it was possible to construct a framework for the assessment of innovation capability performance on Brazilian low-tech small business. The performance perspectives, coupled with performance factors proposed by [24] and evaluation parameters found in the literature, enabled the construction of the model, as presented in Table 1.

Considering Table 1, it is important to highlight that some performance factors and evaluation parameters have been adjusted, guaranteeing alignment and conceptual compatibility between the propositions of the different authors. Next, an analysis of redundancy and conceptual overhead was performed, eliminating contradictory or repeated ideas.

In this way, Table 1 presents a balance between the proposition of the four performance perspectives [17], the performance factors extracted from [24] and the parameters appropriate to their measurement, as suggested by [23]. From the complementary contributions on the evaluation parameters [25, 26, 27, 28, 29, 30, 31], the framework creates a conceptual framework 'customized' to the Brazilian situation for the measurement of innovation performance resulting from innovation capability in micro and small low-tech enterprises.

Table 1 – Perspectives, performance factors and evaluation parameters

<table>
<tr><th>Perspective</th><th>Performance factors</th><th>Evaluation parameters</th></tr>
<tr><td rowspan="8">Operational</td><td>• Increase in quality of goods and services.</td><td rowspan="2">product quality; product performance; process quality; defects; waste or scrap; suppliers; reliability of delivery; dependability</td></tr>
<tr><td>• Increase in efficiency or speed of delivery and/or distribution of goods or services.</td></tr>
<tr><td>• Increase of the range of goods and services.</td><td rowspan="4">manufacturing effectiveness; use of resources; volume flexibility; introduction of new products; computer systems; future growth; product innovation</td></tr>
<tr><td>• Increase of flexibility in production or provision of services.</td></tr>
<tr><td>• Increase in production capacity or provision of services.</td></tr>
<tr><td>• Improvement in communication and interaction between different business activities.</td></tr>
<tr><td>• Reduction of production times.</td><td rowspan="2">work in progress; outputs; cycle times; delivery time; productivity</td></tr>
<tr><td>• Reduction of response time to consumer needs.</td></tr>
<tr><td rowspan="3">Customer satisfaction</td><td>• Increase of visibility or exposure of products.</td><td rowspan="3">image of brand or company; integration with consumers; user problems; product use; service returns; complaints</td></tr>
<tr><td>• Improvement of the ability to adapt to different customer demands.</td></tr>
<tr><td>• Development of strong relationships with consumers.</td></tr>
<tr><td rowspan="2">Human Resources</td><td>• Improvement of working conditions.</td><td rowspan="2">security and health; staff turnover; work efficiency; relationships between employees; involvement of staff; employee skills</td></tr>
<tr><td>• Improvement of health and safety.</td></tr>
<tr><td rowspan="7">Financial</td><td>• Reduction of unit production costs.</td><td rowspan="7">inventory performance; orders or notes issued; profit or profitability; volume of business; fixed costs; cash flow; sales or value added; converted quotations; revenues; market share</td></tr>
<tr><td>• Reduction of operational costs for the provision of services.</td></tr>
<tr><td>• Increase or maintenance of market share.</td></tr>
<tr><td>• Entry into new markets.</td></tr>
<tr><td>• Increase of return on invested capital.</td></tr>
<tr><td>• Increase of revenue or turnover.</td></tr>
<tr><td>• Improvement of financial performance or profit margins.</td></tr>
</table>

5. CONCLUSIONS

The framework is an intermediate product of a broader research project, whose objective is the construction of a reference model for the maturity of innovation capability in small low-tech companies. However, although it is in the initial stages of its development (since it is currently in its validation process), presents some potentialities. In theoretical terms, it offers a representation of the evaluation parameters of innovation performance resulting from innovation capability of small Brazilian companies, integrating different perspectives from different authors. This theoretical framework may be useful for several future studies in the Brazilian context and even in other developing economies, especially in the fields of operations management, economic aspects of logistics and customer service.

In practical terms, it can be an important tool for decision-making, at the management level, in small low-tech companies that aim to increase their innovation capabilities. Complementarily, and perhaps more importantly, the model can be used by institutions and organizations to support the development and competitiveness of Brazilian companies, as an instrument for evaluating and orienting investments, projects and subsidies to small enterprises, especially low-technology ones. The model can even, from customizations and adaptations of use, be employed in other sizes of companies and technological contexts, such as in large research and development companies.

In summary, it is evaluated that the framework has potentially diverse applications, being able to generate benefits for small companies as well as support organizations, increasing competitiveness and performance through differentiations and innovations based on mechanisms of management and performance independent of formal research and development practice. In addition, from simple and inexpensive adaptations, the model can be expanded even to companies inserted in contexts other than their primary use domain, being able to amplify their potential benefits to other companies of different sizes and levels of technological dynamism.

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OPTIMAL IMMUNIZATION STRATEGIES FOR GROUPS AT RISK IN VACCINE SUPPLY CHAIN MANAGEMENT

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Abstract

Annual influenza epidemics cause great losses in human and financial terms. Vaccination is the most effective way of protecting people from being infected. However, the impact of vaccination on the disease spread is dependent on the chosen immunization strategy and on functional, end-to-end vaccine supply chains *and logistics systems. This paper aims to determine the optimal combination of the various immunization strategies that lead to decrease of the disease burden. A supply-chain based model is proposed to address this problem. Computational results show that targeted vaccination significantly outperforms other strategies and prevails over them in terms of cost and efficacy.*

Keywords: *supply chain risk management, disaster logistics, operations management and scheduling*

1. INTRODUCTION

Influenza is an acute respiratory illness that rapidly spreads in seasonal epidemics and annually imposes great losses in both human lives and financial expenses. According to the World Health Organization (WHO) Global Influenza Surveillance and Response System [1], the impact of influenza in the USA only is currently estimated to be 25-50 million cases per year, leading to 150,000 hospitalizations and 40,000 cases of death. The average global burden of pandemic influenza in the rest of the world may be up to about 4-5 million cases of illness and 250,000-500,000 deaths annually. The WHO reports that costs in terms of healthcare, lost days of work and education, and social disruption have been estimated to vary between $1 million and $6 million per 100,000 inhabitants yearly in industrialized countries [1].

Vaccination is known as one of the most effective and widely distributed means of protecting people from being infected by infectious diseases (see [1]-[6], among others). In particular, the influenza vaccination can significantly reduce the transmission rate of infection from infected to the susceptible individual thereby decreasing the disease spread. This, in turn, results in lower morbidity and mortality among the population.

The effectiveness of nation-wide vaccination programs heavily depends on the structure and functioning of the corresponding vaccine supply chain (VSC). The role of the VSC is three-fold: (a) to ensure effective vaccine storage, handling, and stock management; (b) to guarantee effective maintenance of logistics management, and (c) to provide rigorous temperature control in the cold chain. The ultimate goal is to ensure the uninterrupted availability of quality vaccines from manufacturer to service-delivery levels so that opportunities to vaccinate are not missed because vaccines are unavailable [7]-[10]. Following studies in [11, 12], this paper is focused on defining the right quantity of the vaccine doses assigned to different population groups at risk of being infected.

2. VACCINE SUPPLY CHAINS

The vaccine supply chain considered in this study includes multiple manufacturers, several distribution centers (DCs), multiple clinics and multiple end-users that are different population groups at risk of being infected. The vaccination process starts at the moment when the World Health Organization (WHO) determines and announces the expected influenza epidemic risks, strain types, vaccine types and production rates (usually, this happens in January of the current year). After that, the vaccine manufacturers initiate the vaccine production process. After being produced, the vaccines should be tested, usually, the test lasts 45-60 days. Assume that the vaccine testing is performed in June-July and that vaccines are packed and ready to be shipped from the manufacturers in August. The planning horizon starts in August and terminates in March of the next year, with a total duration of 33 weeks. Details of the vaccine supply chain are given in [11]-[12].

Figure 1 borrowed from [11] schematically displays the main components of the vaccination supply chain, and material and information flow. Physical flows are marked by thick arrows; information flows are in broken lines. The set of DCs and the set of clinics are two main collective stakeholders ("players") in the healthcare organization (HCO), each having its own replenishment/service function.

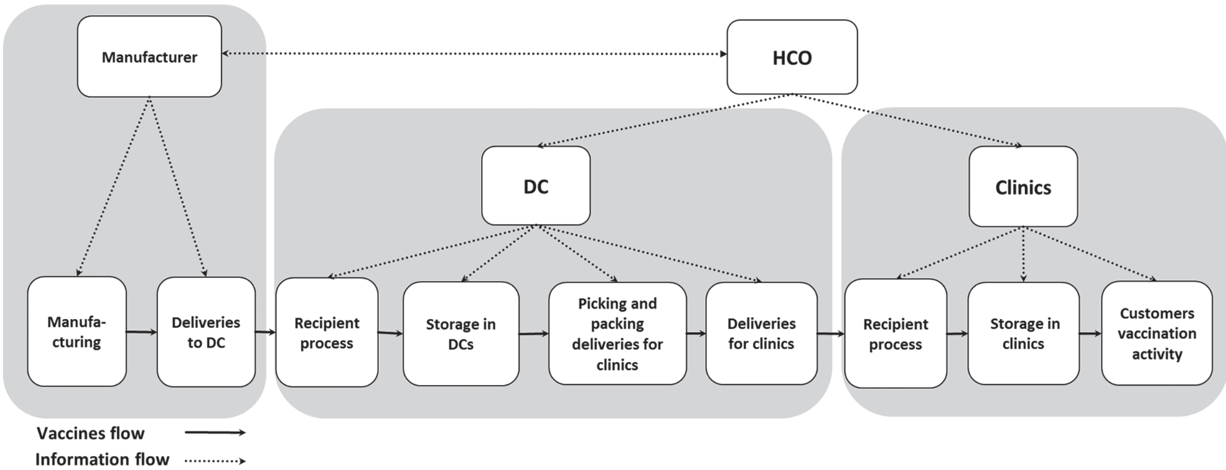

Figure 1 – Main supply chain components and process flows (the source: [11])

In order to improve the overall quality of vaccination services, a set of strategical decisions is to be done by the HCO before the start of the influenza vaccination season. In particular, the HCO is to decide how many vaccine doses should be ordered so that to minimize the total VCS costs (including direct/indirect medical/non-medical costs) while keeping the customer satisfaction and medical efficacy at predetermined levels. The customer satisfaction is associated with the public benefits of vaccination, i.e., an expected decrease in the number of lost working hours, decrease of visits to doctors and improvement of medical service during the influenza season. On the other hand, the medical efficacy is an integral characteristic of medical aspects of the vaccination program that are explicitly expressed by medical staff and medical organizations.

Since the population is heterogeneous (with respect to age, health conditions, and so on), the risk to be infected is varied from individual to individual. Therefore, in order to decrease the disease burden for less protected segments of the population (e.g., infants, seniors, medical personnel, etc.), it is on responsibility of the HCO to define what is a proportion of the vaccine doses to be allotted from the total ordered amount to each risk group of population. This decision strongly depends upon the choice of the vaccination strategy.

3. VACCINATION STRATEGIES

The right quantity of vaccines and, consequently, a major impact of influenza vaccination on the disease propagation in the VSCs is heavily dependent on the immunization strategies. For instance, the mass vaccination, wherein the aim to vaccinate large population groups over a short period of time, seems to be the most effective strategy when the budget is unlimited. However, in the real life, when the resources are scarce, such type of strategy is impractical. On the other hand, the random immunization means to randomly select a fraction of individuals to be vaccinated without accounting for their heterogeneity (age, occupation and so on). Such a strategy can lead to the vaccination of sustainable to disease individuals or persons who are in general isolated from the main mass of the population. Consequently, the impact of the random immunization on preventing the disease spread may be minor. Contrary to the mentioned immunization strategies, the targeted vaccination is directed toward the high-risk groups of individuals, which can be heavily affected by the disease (such as, e, g., elderly people, children, people with chronic illnesses, pregnant women) as well as the groups responsible for the disease spread (for instance, medical personal). Such a strategy allows to better utilize the scarce resources, such as vaccines, logistics resources, and a budget.

During the last decades, the effectiveness of the targeted vaccination was studied based on a variety of approaches. However, the literature devoted to the mathematical models for such type of vaccination still remains comparatively scarce. In particular, in [6, 7], the authors focused on identifying optimal vaccine allocation strategies to reduce influenza morbidity and mortality within the age-structured population. By implementing simulation, they found that vaccinating either younger children and older adults or young adults averts the most deaths. Similar results are obtained in [8].

In order to determine the optimal vaccination strategies for the heterogeneous population under uncertainty, the authors in [10] use a stochastic programming model. This model is an extension of the linear programming model proposed in [9] in which some parameters (e.g., vaccine efficacy and contact rate) are treated as random variables. The decisions regarding the number of individuals in each age group of the population that should be vaccinated are based on the relative infectivity and susceptibility of people in a group. A drawback of the paper is that the impact of the vaccination strategy on public benefits and medical efficacy is not considered. The authors in [16] find that prioritizing individuals on the basis of age and co-morbidities in along with considering individual infection history may have a greater impact on disease reduction in targeting and promoting influenza vaccinations. The advantage of the targeted vaccination was also shown for the non-influenza diseases (e.g., respiratory syncytial virus, see [15]), wherein vaccination of children less than 5 years old is the most effective strategy to avert disease in children and elderly.

While the authors in [6]-[8] consider only the impact of a vaccination strategy on epidemiological and economic outcomes, the present paper considers a more general model. Specifically, the optimal vaccination policies to minimize the total costs associated with vaccination are sought for, whereas the public benefits and medical efficacy are to meet a predefined level defined by decision makers. Similarly to [11-12], the new mathematical model includes public benefits and medical efficacy. At the same time, the present paper extends [11-12] by eliciting the impact of optimal vaccination strategies for each high-risk population sub-group. Moreover, the computational experiment comparing different types of immunization strategies (mass, random and targeted) is carried out demonstrating the advantages of the targeted strategy.

4. PROBLEM DESCRIPTION AND MATHEMATICAL FORMULATION

We consider influenza transmission and vaccination in a VSC containing a number of different risks-groups. The disease transmission takes place both inside the group (i.e., between the group's members) and between the different risks-groups as well. The population groups are heterogeneous (in the sense that the number of members in each group may be different); each group includes individuals with similar rates of susceptibilities and risks of morbidity and mortality. Most groups are assumed to be at high risk.

The main purpose of the proposed mathematical model is to find an optimal combination of different vaccination strategies for each risk group to prevent the disease outbreak. Note, that different individuals in the same risk group can be vaccinated by various immunization strategies. For instance, for some proportion of the individuals, one can use targeted vaccination, whereas the remaining persons are vaccinated under the mass or random immunization program. To estimate the effectiveness of the vaccination program, the researchers usually use a so-called post-vaccination reproduction number. This is the number of secondary cases that an initial infective can generate in the community of the susceptible individuals with partial vaccine coverage. When the number is less than one this means that the disease becomes endemic (i.e., the disease fades away with a time without additional interventions). Otherwise, the rate of disease spread increases and infection becomes an epidemic.

The specificity of the mathematical model to be designed is the presence of several conflicting criteria. The multi-criterion decision problem means that the model includes in the form of multiple objective functions three main characteristics: medical efficacy, public benefits, and vaccination program costs (see, for example, [9, 10]). Each of the three primary characteristics may be divided, in turn, into several partial objectives (called sub-objectives). Note, that in the suggested mathematical model, the public benefits are handled with the help of a general function called a vaccination coverage of the susceptible population. It implies that the larger the vaccination coverage, the fewer hospitalization cases are expected due to morbidity. Further, the medical efficacy is associated, in particular, with the total amount of hours needed for vaccination. The smaller the latter number, the higher the medical efficacy. Moreover, unlike the models considered in [9, 10], the best min-cost combination of the vaccine strategies is sought for.

The main initial (or strategic) decision variables treated in the considered VSC are the following:

- inventory size in the healthcare organization (HCO) r in period t, $t = 1,\dots, T$, $r = 1,\dots, R$;
- inventory size in clinic i at the end of period t, $i = 1,\dots, I$, $t = 1,\dots, T$;
- delivery (shipping) quantity of vaccines from manufacturer m to HCO r in period t;
- the delivery quantity of vaccine units from HCO r to clinic i in period t;
- the number of unused vaccines in sub-group j in period t in clinic i;
- vaccine consumption by sub-group j in clinic i in period t;
- amount of vaccine required by HCO r at period t.

Denote by $C(x)$, $E(x)$, and $B(x)$ three criteria above, that is, the vaccination costs, vaccination efficacy, and public benefits. In formal terms, a multi-criterion vaccination planning problem can be represented in the decision space of n variables as follows:

$$(\text{Min } C(\boldsymbol{x}), \text{Max } E(\boldsymbol{x}), \text{Max } B(\boldsymbol{x})) \tag{1}$$

$$\boldsymbol{x} \in \boldsymbol{X}, \ \ \boldsymbol{X} \subseteq \boldsymbol{R}^n \tag{2}$$

where $\boldsymbol{x}$ is the decision variable vector of size n, and $\boldsymbol{X}$ is the feasible set of variables.

For solving the multi-criterion problem (1)-(2), in this paper the method of principal criterion (also known as an epsilon-constrained approach, see [17]) is used wherein the vaccination costs are taken as the principal criterion and two other criteria considered as constraints with the right-hand side values provided by medical experts.

The following tactical decision variables, similar to those in the paper [10], are introduced:

x_{fv} - the proportion of the vaccinated individuals in the group at risk f under the policy v, where $f \in F$, $v \in V$. F is the set of risk-groups, and V the set of vaccine strategies (such as the mass vaccination, the random vaccination, the targeted vaccination, etc.)

Parameters in the model are the following:

w_f - the proportion of the number of individuals in a risk-group *f* from the entire population;
ω_{fv} - threshold (a minimal value) for a number of members from risk-group *f* to be vaccinated under strategy *v*; by allotting different values to ω_{fv}, various vaccination strategies can be derived;
α_{fv} - impact on disease spread in risk-group *f* vaccinated by policy *v* (see [9, 10], for details);
μ_F - the average size of the risk-group;
M - number of available vaccine doses *v*;
c_v - cost of vaccination strategy *v*;
η_v - the average time for vaccination under strategy *v*;
c_f - required vaccination coverage for risk-group *f*;
H_v - available medical personnel hours allotted to each vaccine strategy *v*.
Parameters for computingare α_{fv} similar to analogous parameters in [9, 10]:
m - the average contact rate of infected people;
u_f - the relative infectivity of individuals in risk-group *f* ;
s_f - the relative susceptibility of individuals in risk-group *f* ;
b - the transmission proportion;
ε - the vaccine efficiency;

$$\alpha_{fv} = mwf\,[u_f s_f\,[(1-b)(w_f - \varepsilon\omega_{fV}) + b\omega_{fv}\varepsilon(1-\varepsilon)] + bu_l s_f(w_f - \varepsilon\omega_{fV})^2]$$

The mathematical model can be now written as follows:

$$Min\ Z = \sum_{f\in F}\sum_{v\in V} c_{fv} w_f x_{fv} \tag{3}$$

subject to:

$$\sum_{v\in V} x_{fv} \le 1, \forall f \in F \tag{4}$$

$$\sum_{f\in F}\sum_{v\in V} a_{fv} x_{fv} \le 1 \tag{5}$$

$$\sum_{v\in V} x_{fv} \ge C_f, \forall f \in F \tag{6}$$

$$\sum_{f\in F} \mathsf{h}_v w_f x_{fv} \le H_v, \forall v \in V \tag{7}$$

$$\sum_{f\in F}\sum_{v\in V} w_f x_{fv} \le M \tag{8}$$

$$x_{fv} \ge 0, \forall v \in V; \forall f \in F \tag{9}$$

The objective function (3) minimizes the total vaccination cost. Eq. (4) ensures that the proportion of the vaccinated individuals in each risk-group *f* does not exceed one. To prevent the epidemic outbreak, constraint (5) holds, that is, the reproduction number is to be less than one. Constraint (6) ensures that the vaccination coverage for the risk-group *f* is no less than the predefined value C_f. Medical personal resource availability is demonstrated by constraint (7). Since the number of vaccine doses is limited, constraint (8) is used. Finally, constraint (9) guarantees that the decision variable is non-negative. Notice that constraint (6) reflects the public benefits whereas constraint (7) is associated with the medical efficacy.

5. COMPUTATIONAL EXPERIMENTS

Consider a fragment of the VSC CLALIT (see [11], [12], for details). The number of different groups at risk is 6 (1 stands for the low-risk group, …, 6 for the high-risk group); the set of vaccine policies includes 3 possible strategies of immunization: mass, random and targeted. The remaining data regarding the contact rate, relative infectivity/susceptibility, and others are borrowed from [10, 11]. The optimal solution of the linear program (3) -(9) is found by using the commercial software GAMS and CPLEX algorithm. The obtained computational results show that the targeted vaccination is superior with respect to the mass and random vaccination strategies as it has a smaller cost and a higher medical efficacy (see Figure 2). Another result is that the most prioritized risk groups are the following: elderly people, children (< 5 years), medical workers, and food-chain workers.

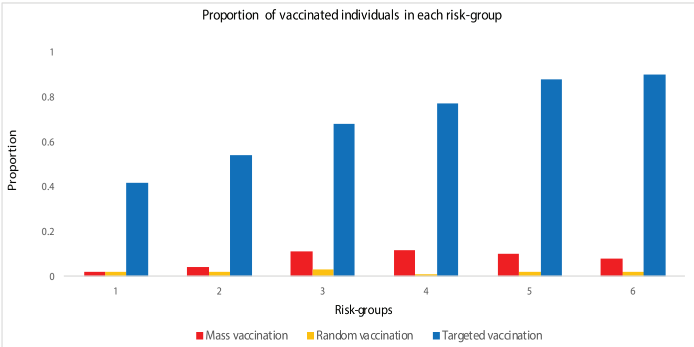

Figure 2 – The proportion of vaccinated individuals in each risk-group

6. CONCLUSION

Although the suggested mathematical model significantly differs from those known in the literature, the computational results obtained are very close to the earlier known ones, namely, the targeted vaccination strategy seems to be superior in comparison with the mass and random strategies (see, e.g., [6], [13]-[14]). It is worth noticing that the suggested model permits to find the best combination of several vaccination policies. In future work, it would be useful to further experiment with wider sets of vaccination strategies and population groups at risk. Moreover, investigating the influence of different transmission rates, e.g., saturated rates, on the optimal vaccination strategies may also be a very promising direction.

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SUSTAINABLE MANAGEMENT OF THE SPACE AS A CONDITION FOR THE DEVELOPMENT OF THE MEDIUM-SIZED CITIES

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Abstract

Medium-sized cities like Oświęcim[1] are shrinking. They face many problems: the ageing inhabitants, the outflow of young people, a high level of migration, insufficient development of entrepreneurship, the polluted environment and the decrease of resources. Oświęcim had the largest number of residents in 1992 – 44,874. In 2016 there were 40,292 inhabitants in, Oświęcim: the number of inhabitants is decreasing year by year.

Currently, the attention of local governments of small and medium-sized cities is directed at undertakings that increase their attractiveness and minimalise the environmental damage. These activities are focused on improving the quality of the environment, spatial arrangement and the quality of life [2]. The author analyses the city of Oświęcim with regard to the aspects mentioned above, trying to prove that the town of Oświęcim follows the path of sustainable development.

There are many issues included in the principles of sustainable development:

- architectural and spatial aspects: improvement of the quality of public space, revitalization and modernization of buildings and technical infrastructure, reduction of their environmental impact, increase in the number of safe and friendly green spaces

- social aspects: activities aimed at maintaining social balance in a given area, logistics of the investment process, including forecasting market needs and satisfying customer expectations

- economic and ecological aspects: green logistics as optimization of the potential of a given place and its use in a proper manner

Keywords: *sustainable management, medium-sized cities, quality of the living environment, green logistics in sustainable development*

1. INTRODUCTION

If the cities in Poland continue to develop in the current consumption and exploitation form, it will result in the disaster related to the quality of urban space and the quality of the natural environment. Consequently, it will lead to the depopulation of cities, urban sprawl, increase of the environment pollution and unfavourable changes in the structure of the population.

Sustainable management of urban space is focused on achieving a high-quality residential environment, minimising ecological damage through modernisation, an increase of the amount of green public areas, improvement of the communication and technical infrastructure, as well as maintaining social balance.

"Balancing is usually interpreted as the fulfilment of arbitrarily quantified – usually technological - balancing indicators in order to achieve progressive, contractual balance states. However, it is about something more: the task is to harmonise the social, economic and ecological goals of actions in the process of maintaining the balance (this is the meaning of the term sustainability) and responding to its disturbances." [3] Sustainable development of the city is the regulatory background for spatial policy in Poland. The idea of sustainable development means striving for balancing and coordinating three factors: environmental, social and economic

development. It is a complex issue, especially within the city, an intertwining dynamic system of spatial, social and economic processes.*"Maintaining a balance between the natural environment and the one created by the man is a prerequisite for creating a healthy, friendly housing environment, in harmony with the green surroundings, the landscape and in the symbiosis of architecture and nature."* [4] Sustainability is defined as a strategy related to the management of the urban areas, which task is, among other things, to minimise the environmental impact of both built-up and natural environment. The vision of the sustainable development of urban space focused on the development of the city combines the activities of planners and designers to manage the process, the aim of which is to create a sustainable, safe, healthy and socially integrated environment.

2. OŚWIĘCIM – ECONOMIC AND INVESTMENT POTENTIAL

Figure 1 – Oświęcim – Old Town bird's eye view
web.um.oswiecim.pl, Town Hall of Oświęcim | Oświęcim – the City of Peace,
City Hall of Oświęcim |Oświęcim - the City of Peace1000 × 666Search Search

Oświęcim is an industrial city. It is located in the Lesser Poland Voivodeship, in Poland, near the important economic regions: the Upper Silesian Industrial District, the Kraków agglomeration and the city of Bielsko-Biała. Due to its location, Oświęcim is very attractive for the development of the investment activities. Business activity is characterised by vast diversity, with the dominant chemical industry, mechanical and electromechanical manufacturing and the production of the building materials. In the period of transformation, starting from 1989, the shrinking of the chemical industry, including Zakłady Chemiczne in Oświęcim, and then Dwory Chemical Company, resulted in the appearance of the empty areas and halls released by the companies. Consequently, the city faced the phenomenon of shrinking of the labour market and the increase of the unemployment.

The appearance of the Municipal Economic Activity Zone and the Oświęcim Business Incubator has led to the creation of the new jobs and the development of the local entrepreneurship. These activities of the city authorities increased the investment attractiveness of the city in the region.

The spatial structure of the city of Oświęcim was determined by the development of the Oświęcim Chemical Company. The construction of the factory resulted in the formation of the large-scale housing, along with accompanying services. All the attention of the local authorities in this period was directed to this part of the city, while no investments were made on the Old Town district (Figure 1).

Oświęcim is a town, whose tradition dates back 800 years. The urban layout and monuments in the old part of the city are a testimony to its history. The Old Town remained underfunded for an extended period, the effects of which are still visible today. This uneven development of the city structure has led to a number of social, economic and environmental problems occurring in this area. The connection of the urban structure of the Old Town with multifunctional urban fabric new lifestyles of the residents, technological and social changes, as well as perceptible environmental changes, explain the growing need of the awareness of environmental protection and the use of resources in a sustainable way.

The adopted research method of the work includes a discussion of the importance of the idea of sustainable development in relation to urban space, and for the rational and harmonious shaping of the city structure. In this context, literature and field studies were carried out. Moreover, it included the analysis of the data stored in the city archives, the review of archival design and photographic materials and implementation of site inspections and interviews with residents, so that it was possible to evaluate the Old Town in the context of sustainable development.

3. SUSTAINABLE DEVELOPMENT OF THE OLD TOWN SPACE IN OŚWIĘCIM

Currently, a lot of attention of the local authorities is directed to the Old Town, improvement of its image and reduction of the environmental damage. Moreover, there are also activities carried out striving to eliminate degraded areas of poor quality of life and residence. In recent years, the Old Town has been modernised. The renovation works of the Piast Castle and the Castle Hill were completed, together with the establishment of the museum. Kościelna street with the square of o. Skarbek were rebuilt and modernised, as well as Bulwary street along with the adjacent parking lot. Furthermore, the Main Market Square along and the accompanying infrastructure were renewed (Figure 2).

Figure 2 – Modernised Main Market Square in Oświęcim

Residential buildings and service are located in the Old Town area. Among the housing buildings as many as 41 come from before 1945, 12 were built in 1946-1989. The age of the development of the Old Town entails the need to carry out renovations, reconstructions, modernisation, or exchange related to the technical condition of the buildings, and their equipment. They use environmentally friendly materials that reduce or eliminate negative impacts on our climate during construction or operation. Pro-ecological activities may result in the possibility of obtaining certificates such as BREEM or LEED. Many of the actions undertaken by the city's authorities are aimed to prevent the problem of decapitalization and devastation of the buildings. There is a tendency to develop "empty tenement houses" of unknown property located in the Old Town area. For instance, devastated tenements at Klasztorna Street and Mały Rynek were renovated and inhabited in 2015. The corner tenement at the Sienkiewicz and Mickiewicz Streets (Figure 3 and 4) was restored and modernised by the Social Building Society. [6] The city has also made significant investments related to the replacement of the old heat sources, regarded as one of the largest emitters of the harmful substances in the city. The projects have increased the energy efficiency of the buildings, led to a reduction of water use, limited the negative impact of the building on human health and the environment throughout its life cycle of the building.

Figure 3 – Oświęcim. Demolished tenement at the corner of Sienkiewicz and Mickiewicz Streets

Figure 4 – Oświęcim. Modernised corner tenement at Sienkiewicz and Mickiewicz Streets

4. SOCIAL BALANCE IN THE OLD TOWN

As far as local self-government is concerned, the priority of sustainable development of local community should include the increase of the quality of life of its residents, as well as ensuring decent living conditions, employment, and the use of free time with a reasonable level of security and environmental standards. Taking into account the European Union's priorities in the field of sustainable development, local authorities should focus on those areas of development that concern climate, health, social exclusion, and ageing.

Oświęcim, like many small and medium-sized cities in Poland, is affected by problems associated with depopulation and the ageing of the local community. [5] The city authorities are trying to prevent the problem of migration of the residents to the outskirts of the town through the development of the empty tenements, and through the allocation of city-owned vacant plots for housing development.

The area of the Old Town is inhabited by 2018 people, which is 5.12% of the total population of the city. The population structure is characterised by a decrease in the number of people in pre-working and working age. This trend has been maintained since 2010. At the same time, the number of people in the post-working age is increasing, which indicates ageing of the population.

The area of the Old Town is characterised by the highest exceeded values of indicators related to recorded offences, in relation to the same data presented for the whole city. Considering the number of inhabitants living in a given area, one can state a large concentration of pathological behaviours and crime. The unemployment is also higher than in other parts of Oświęcim and indicates the scale of this problem. [6]

In this situation, maintaining the social balance is of the highest importance. It applies to:

- the balance of the age profile,

- the balance of housing types and properties,

- the balance of types and sizes of the households,

- the social stability of the population.

Housing stability will make the Old Town sustainable from a social point of view. Increasing the number of residents who own property rights to the occupied property contributes to the perception of a given place as more stable. Urban activities carried out by the Social Housing Association (TBS) related to the development of "empty tenement houses, unknown properties" favourably improve the structure of the population living in this area. They support housing needs, for people who, due to their income, are located in a specific segment of the social structure. [7] TBS actions contribute to filling the gap connected with the middle-income and middle-age group of the residents.

These actions can be called logistic – understood as so-called Green Logistics, giving the opportunity to predict the potential of a given place with regard to social goals, beneficial not only because of the prospects of development but also because of maintaining social balance in a given area (in reference to sustainable development).

The urban environment is the background for all kinds of neighbourly relations. The population living in a given place, a given neighbourhood, in this case, the Old Town constitutes a specific cultural community, with shaped habits, customs and norms. Urban spaces are a visual content of the spatial environment and social dimensions. The image of the local community is of great importance to the city because it attracts people, investors and tourists. Sustainability in the social perspective in Oświęcim is understood as supporting social "reconciliation", increasing the housing stability and extending the participation of the residents in the responsibility for the neighbourhood.

Places where residents meet, available to all social groups, play a vital role in creating an active local community. Parks, squares are places of rest, children's play, places of chats, meetings, where one can calm down emotion also contribute to the improvement of the health and positively influence the quality of the environment. [8] The actions of the city self-government are aimed at activating the areas of the Old Town, along with the recreational spaces along the Soła River, in order to increase the number of the visiting tourists, who are currently mainly focused on the Auschwitz Museum. The Old Town is a vital part of the city when it comes to the development of the tourism. Implementation of the Ghost Bridge, a unique project of Jarosław Kozakiewicz would undoubtedly upsurge the number of the tourists visiting the Old Town (Figure 5).

Figure 5 – Ghost Bridge

5. CONCLUSIONS

Most of the methods currently used in the contemporary design and creation of residential complexes in urban development, apply planning solutions of an ecological nature, having the character of Green Logistics. Environmentally friendly materials are used, and the construction process is carried out in an environmentally friendly manner. These activities give the opportunity to obtain certificates such as BREEM or LEED, which increase the prestige of the investment.A sustainable urban environment provides more opportunities for people living in it, with regard to equality and social cohesion, economic growth, high-quality urban environment and better environmental results. Sustainable development of the city space contributes to limiting the uncontrolled development of the town, providing better transport infrastructure, protection of the cultural areas, protection of the green urban regions including cycling and walking paths, etc. Sustainable development in the Old Town of Oświęcim in the context of the expected results concerns the following aspects:

- architecture – buildings that can undergo modifications related to the function, and the use of new technologies and materials.

- social – design for people and to meet their needs, integration of the residents, social balance, social participation – participation of the residents in the investment process.

- ecological – use of materials susceptible to recycling, modern technologies, the design of zero-energy buildings with proper thermal protection.

- economical – minimalised area consumption, concern for low operating costs, cheap material acquisition, the durability of materials.

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QUANTITY FLEXIBILITY CONTRACT FOR COORDINATING SUPPLY CHAIN IN PRESENCE OF UNCERTAINTY

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Abstract

The purpose of this paper is to analyze the effectiveness of Quantity Flexibility Contract (QFC) as Supply Chain (SC) coordination mechanism under market demand and spot market uncertainty, by measuring such effectiveness in terms of the profits gained by each actor under QFC with respect to the profits obtained under traditional contract. In so doing and by varying the contract terms and implementation conditions, we ensure that the QFC is chosen only when it ensures a win-win condition, namely it improves the profits of both parties. A simulation-based research has been carried out in order to address this issue. In particular, a real options-based model has been developed to model and quantify the benefits granted by flexibility incorporated into the QFC, for both SC actors. A series of experiments consisting of different experimental settings was designed in order to investigate the effect that contract terms and implementation conditions have on the benefits of both actors and on the entire system. The proposed model's application and the experiments have been illustrated by considering an SC coordination problem handled by an example company operating as retailer in a European country through QFC.

Keywords: *supply chain coordination, uncertainty, flexible supply contract, simulation*

1. INTRODUCTION

Economic globalization, product proliferation, and technology progress increase the uncertainty of customer demands and market prices across many industry sectors. Management of demand and price uncertainties has become crucial for the survival of many companies. Several supply chain management tools and methods have become available to help companies streamline their supply chain operations. Supply chain contracts are proposed and developed to assist supply chains to achieve better coordination and performance. These include quantity flexibility (QF) contracts [1], backup agreements, buy back or return policies, incentive mechanisms, revenue sharing (RS) contracts, allocation rules, and quantity discounts [2, 3]. QF is a supply contract that provides the buyer with the flexibility to adjust future orders to a later date and at a favorable price after an improved forecast of the customer demand or accurate information about the spot supply market price become available. Given to these characteristics, QFC may allow all the autonomous entities to reach higher profits compared with what would happen if there were no such contract (i.e., the so-called win-win condition). It may eliminate inefficiency by driving local actors to behave in the interests of the global SC rather than their own, and regulate how savings can be split and risks distributed fairly among all the actors on the SC chain. At the same time, under QFC the supplier formally guarantees the buyer a specific safety cushion in excess of estimated requirements, thus providing some certain flexibility on the quantity of their products. The supplier allows the buyer to change the quantity ordered after observing the actual demand as well as favorable fluctuation of the spot market price. The supplier benefits by having a smoother production schedule as a result. While several studies have investigated the QFC as coordination mechanism of decentralized SC, they provide little emphasis on their ability to give a protection against price and demand uncertainties.

The purpose of this paper is to analyze the effectiveness of QFc as SC coordination mechanism under market demand and spot market uncertainty, by measuring such effectiveness in terms of the profits gained by each actor under QF contract with respect to the profits obtained under traditional contracts. In order to accomplish this objective, we operationalize QFC as an option-based contract. In fact, operationalizing a contract of this type requires modelling the managerial flexibility of the retailer to deviate from the committed quantity within a pre-defined range, without paying any penalty, in case of demand fall, and with the insurance of fixed price, in case of demand rice; and to decide to reduce the purchased quantity up to the minimum quantity and buy from the alternative source (i.e., the spot supply market) in case of favorable spot market price, whenever such choice proves convenient. Traditional approaches, such as those based on Discounted Cash Flows (DCF) analysis (especially NPV), cannot be used to model this managerial flexibility. Consequently, they cannot be used to price the value of the investigated QFC. It is essential that flexibility be quantified, and any attempt to do so almost naturally leads to the concept of options [4]. Regarding option pricing, the methods traditionally proposed in the literature on real options are financially-based approaches to option pricing (such as [5,6] and others). However, they often turn out not to be workable in practice [7]. Simulation-based research is preferred for complex and expanded problems with several factors and interactions, as it is in supply chain settings [8].

2. ROV SIMULATION MODEL FOR QFC

In this section we consider a two-stage supply chain, where each node represents an independently managed organization. The first stage consists two nodes: a manufacturer that holds a relationship with a retailer through a QF contract, and the spot market which represents the alternative supply market for the retailer. The second stage consists of only one node, namely the retailer, serving an uncertain market demand. The analysis may be easily extended to more complex supply chains without undermining the foundation principles of the model.

We consider a multi-period problem where the retailer first plans procurement of products from the manufacturer for the next period based on the current demand forecast and then makes the actual purchases based on the updated information of the uncertain demand and the fluctuating price of the spot market.

2.1. Mathematical formulation

Let Q* be the fixed periodical quantity ordered by the retailer, at each order time t, up to the contract duration T. Contrarily to the traditional contract, the QFC allows the retailer to make the actual purchase, at each t, according to the updated information on the actual demand and spot market price. In each period t, the retailer can adjust the order quantity by increasing – up to a maximum quantity $Q^*(1 + \alpha)$ – or decreasing – up to a minimum quantity $Q^*(1 - \beta)$ – the purchased quantity without paying any penalty. For all the purchased quantities ranging in such interval, the retailer has to pay a price Cf to the manufacturer engaged in such QFC. The manufacturer is not the only source for the retailer, which may still decide to buy the needed quantity from the spot supply market at a price Cm. The flexibility provided by the QFC consists operatively in the right of the retailer to deviate from the committed quantity within the pre-defined range $[Q^*(1 - \beta); Q^*(1 + \alpha)]$, without paying any penalty, in case of demand fall, and with the guarantee of buying at a fixed price, in case of demand rice; and to decide to reduce the purchased quantity up to the minimum quantity $Q^*(1 - \beta)$ and buy from the alternative source (i.e., the spot supply market) in case of favorable spot market price, whenever such choice proves convenient. In terms of real options, this corresponds to a real (put) option hold by the retailer, where the saving obtained when the retailer does not buy from the manufacturer is the exercise price of the option. Hence, this put option will be exercised whether the price paid to buy from the spot supply market (i.e., the underlying asset of the option ST) is lower that the exercise price. The sunk cost of the flexibility, namely the transaction costs for implementing the contract, the higher costs for maintaining the contract, etc., is the cost of the option (option premium).

In order to operationalize and quantify the differential profits gained by the manufacturer and the retailer under the QFC compared to the traditional contract, the model adopts the following parameters:

t = 1, …, T	order time (week, month, quarter, according to the order characteristics), up to the total time horizon T, which depends on the length of the QFC
Q^*	the fixed periodical quantity ordered by the retailer, at each order time t, which can be revised when the retailer makes the actual purchase
α and β	flexibility parameters which determine the range within which the quantity purchased can vary with respect to the ordered quantity
P_v	final price of the product sold by the *retailer* to the final customer
C_f	fixed price paid by the retailer to the manufacturer for each unit purchased within the flexibility range $[Q^*(1-\beta); Q^*(1+\alpha)]$
C_T	price paid by the retailer to the manufacturer for each unit purchased under the traditional contract, which is generally the average actual price changed by the market when the contract is stipulated.
P_{pm}	penalty due to the manufacturer for each unit of product the retailer purchases less than the committed quantity Q^*, under the traditional contract. It also corresponds to the penalty paid to the manufacturer for each unit the retailer purchases less than the minimum quantity $Q^*(1-\beta)$ under the QFC.
C_p	the unit variable manufacturing cost of the manufacturer, under the traditional contract and the QFC. It includes: materials, energy and other variable costs.
C_c	fixed costs of the manufacturer, computed for the period related to the order time (week, month, quarter, according to the order characteristics). It is function of the production capacity and includes the investment costs in tangible (building, equipment, etc.) and intangible (patents, know-how, etc.) assets. Since the QFC requires a greater production capacity to deal with the flexibility of the supply contract than the traditional one, it generally results that $C_c^{TC} < C_c^{QFC}$.
D(t)	market demand at each t
δ_m	actual share of the demand supplied by the spot supply market when the retailer decides to purchase from this alternative source.
$C_m(t)$	market price that the retailer pays at each t when he/she buys from the spot supply market
$C_{st}(t)$	stockout costs due to the inability of the retailer to fulfil the customer requirement. For example, with no inventory of a certain item, a customer order will not be fulfilled.
i_t	periodical discount rate (calculated from the annual discount rate i)

We also made the following assumptions. i) The availability of the spot market δ_m to provide the required quantity decreases when the market demand D(t) increases, according to an exponential probability distribution $f(D(t)) = \lambda e^{-\lambda \cdot D(t)}$, where λ measures the gradient of the function. We assume that an increase of the market demand may be considered a signal of growth of the entire sector's demand, this in turn will increase the total demand on the supply market. Hence, in the short period (as it is between two order time t, t+1), when it is not possible to increase the productivity capacity, the availability of the spot supply market to fulfil such a growing demand decreases. ii) The stockout costs include all the costs charged by the retailer when she/he is unable to fulfil the customer order, such as lost sales, penalty, loss of customers, loss of image, etc. Although they are important costs in SCM practice, they are often neglected for their difficult objective estimation (Wu et al., 2008). To investigate the effectiveness of the QFC to coordinate the two-stage supply chain (SC) in presence of uncertain market demand and spot market price, four basic scenarios may be identified.

Scenario 1: the market demand is higher than the maximum quantity $Q^*(1+\alpha)$ that the retailer can order at fixed price under QFC.

Scenario 2: the market demand ranges between Q* and the maximum quantity $Q^*(1+\alpha)$.

Scenario 3: the market demand is between Q* and the minimum quantity $Q^*(1-\beta)$.

Scenario 4: the market demand is lower than the minimum quantity $Q^*(1-\beta)$.

To quantify the differential profits of both actors, manufacturer and retailer, under the QFC compared to the traditional contract, we consider only Scenarios 2 and 3, since the other two Scenarios have the same characteristics of the traditional contract, without any differential profits provided by QFC. To put it differently, only in the Scenario 2 and 3 the QFC provides different profits for the two SC actors compared to the traditional contract, since it provides to the retailer the flexibility to revise the order quantity Q* and make the actual purchase, at each t, according to the updated information on the actual demand and the spot market price. Also, we consider Scenario 2 and 3 separately since in the traditional contract the retailer's behavior in these two scenarios is different. In the first (Scenario 2) ($Q^* < D(t) < Q^*(1+\alpha)$), the retailer will purchase the quantity exceeding Q* from the spot supply market without any insurance of availability. Contrarily, in the latter (Scenario3) ($Q^*(1-\beta) < D(t) < Q^*$), the retailer has to pay a penalty for the shortfall. In the following, the profits of the QFC compared with the traditional contract are modeled, for the manufacturer and the retailer, in both scenarios.

Scenario 2 - $\underline{(Q^* < D(t) < Q^*(1+\alpha))}$

In traditional contract the retailer will purchase the additional quantity $(D(t)-Q^*)\delta_m$ from the spot supply market at $C_m(t)$, based on the market availability, and will bear the stockout costs $C_{st}(t)$ for the residual quantity which is not delivered to the customer $(D(t)-Q^*(1-\delta_m)$. The retailer's profit in the traditional contract Π_R^{TC}, Scenario 2, is computed at each t by equation (1).

$$\Pi_R^{TC} = P_v Q^* + P_v(D(t)-Q^*)\delta_m - [C_T Q^* + C_m(t)(D(t)-Q^*)\delta_m + C_{st}(t)(D(t)-Q^*)(1-\delta_m)] \quad (1)$$

In QFC, the retailer may receive all the needed quantity (up to $Q^*(1+\alpha)$) from the manufacturer at Cf; he also has the possibility to reduce the quantity purchased under QFC up to $Q^*(1-\beta)$ and buy from the spot market at $C_m(t)$, whenever it is available and convenient.

In terms of real options, the retailer will decide to exercise the option if the saving when he does not buy from QFC (namely, the exercise price of the option, $C_f[D(t)-Q^*(1-\beta)]\delta_m$) is higher than the cost paid to purchase that quantity from the spot supply market (namely, the stock price of the option, $C_m(t)\,[D(t)-Q^*(1-\beta)]\delta_m$)). The retailer's decision to exercise the option will depend on the expected payoff of the option computed as in (2).

$$Option\ payoff = max\{C_f[D(t)-Q^*(1-\beta)]\delta_m - C_m(t)[D(t)-Q^*(1-\beta)]\delta_m; 0\} \quad (2)$$

Hence, according to (2), the retailer will decide whether to exercise the option (OQFC = 1) and buy the quantity $[D(t)-Q^*(1-\beta)]\delta_m$ from the spot market at $C_m(t)$, and the remaining quantity $[D(t)-Q^*(1-\beta)](1-\delta_m)$ at Cf from the manufacturer under the QFC.

The retailer's differential profit gained under QFC compared to traditional contract at each t, $\Pi_R^{(QFC-TC)}(t)$, in Scenario 2, is computed by (3) or (4), depending on the exercise of the option (OQFC = 1) or not (OQFC = 0) respectively.

$$\Pi_R^{(QFC-TC)}(t) = \begin{cases} P_v[D(t)-Q^*(1-\beta)] - C_m(t)[D(t)-Q^*(1-\beta)]\delta_m - C_f[D(t)-Q^*(1-\beta)](1-\delta_m) + \\ \quad -\{P_v Q^*\beta + (P_v - C_m(t))[D(t)-Q^*]\delta_m - C_{st}(t)[D(t)-Q^*](1-\delta_m) - C_T Q^*\beta\} \end{cases} \quad if \ \ O_{QFC} = 1 \quad (3)$$

$$\Pi_R^{(QFC-TC)}(t) = \begin{cases} P_v[D(t)-Q^*(1-\beta)] - C_f[D(t)-Q^*(1-\beta)] - \\ +\{P_v Q^*\beta + (P_v - C_m(t))[D(t)-Q^*]\delta_m - C_{st}(t)[D(t)-Q^*](1-\delta_m) - C_T Q^*\beta\} \end{cases} \quad if \ \ O_{QFC} = 0 \quad (4)$$

The retailer's differential profit gained under QFC compared to traditional contract over the total time horizon T, which depends on the length of the QFC, is computed as the sum of the discounted profits gained at each t (with t = 1, …, T), as in (5).

$$\Pi_R^{(QFC-TC)} = \sum_{t=1}^{T} \frac{\Pi_R^{QFC}(t)}{(1+i_c)^t} \quad (5)$$

The manufacturer's profit in the traditional contract Π_M^{TC} at each t is computed by equation (6):

$$\Pi_M^{TC}(t) = C_T Q^* - C_p Q^* - C_c^{TC} \tag{6}$$

Where C_c^{TC} are the fixed costs borne by the manufacturer computed for the period related to the order time t. The differential profit that the manufacturer gains under QFC compared to the traditional contract is affected by the retailer's decision to exercise the option and the availability of the spot market to provide the required quantity. When the retailer exercises the option, the manufacturer's differential profit decreases since the quantity sold to the retailer decreases to $(1 - \delta_m)[D(t) - Q^*(1 - \beta)]$). When the retailer does not exercise the option, the manufacturer gains a higher profit which is the difference between its revenues $C_f[D(t) - Q^*(1 - \beta)]$) and its production costs $(C_p[D(t) - Q^*(1 - \beta)] + C_c^{QFC})$. The differential profit of the manufacturer in Scenario 2 under QFC compared to the traditional contract $\Pi_M^{QFC}(t)$ is computed, at each t, by (7) or (8), depending on the exercise of the option by the retailer (OQFC = 1) or not (OQFC = 0) respectively.

$$\Pi_M^{(QFC-TC)}(t) = C_f[D(t) - Q^*(1-\beta)](1-\delta_m) - C_p[D(t) - Q^*(1-\beta)](1-\delta_m) - C_c^{QFC} - [(C_T - C_p)Q^*\beta - C_c^{TC}] \quad if \quad O_{QFC} = 1 \tag{7}$$

$$\Pi_M^{(QFC-TC)}(t) = (C_f - C_p)[D(t) - Q^*(1-\beta)] - C_c^{QFC} - [(C_T - C_p)Q^*\beta - C_c^{TC}] \qquad if \quad O_{QFC} = 0 \tag{8}$$

The manufacturer's differential profit gained under QFC compared to traditional contract over the total time horizon T, which depends on the length of the QFC, is computed as the sum of the discounted profits gained at each t (with t = 1, …, T), as in (9).

$$\Pi_M^{(QFC-TC)} = \sum_{t=1}^{T} \frac{\Pi_M^{(QFC-TC)}(t)}{(1+i_c)^t} \tag{9}$$

Scenario 3 - <u>$(Q^* - \beta) < D(t) < Q^*$</u>)

In traditional contract the retailer will not have the flexibility of purchasing less than the committed quantity Q^*. In such case, in fact, the retailer has to pay the (unitary) penalty P_{pm} to the manufacturer for the shortfall. The retailer's profit in the traditional contract Π_R^{TC} in Scenario 3 is computed at each t as in (10).

$$\Pi_R^{TC}(t) = P_v D(t) - [C_T D(t) + P_{pm}(Q^* - D(t))] \tag{10}$$

Contrarily to traditional contract, in QFC the retailer may revise the purchased quantity without paying any penalty: he/she has the possibility to reduce the quantity purchased under QFC up to $Q^*(1 - \beta)$ and buy from the spot market at $C_m(t)$, whenever it is available and convenient. In terms of real options, the retailer will decide to exercise the option if the saving gained by not buying from the manufacturer under QFC (namely, the exercise price of the option, $C_f[D(t) - Q^*(1 - \beta)]\delta_m$)) is higher than the cost paid to purchase that quantity from the spot supply market (namely, the stock price of the option, $C_m(t)\,[D(t) - Q^*(1 - \beta)]\delta_m$)). The retailer's decision to exercise the option will depend on the expected payoff of the option computed as in (11).

$$Option\ payoff = max\{C_f[D(t) - Q^*(1-\beta)]\delta_m - C_m(t)[D(t) - Q^*(1-\beta)]\delta_m; 0\} \tag{11}$$

Hence, according to (11), the retailer will decide whether to exercise the option (OQFC = 1) and buy the quantity $[D(t) - Q^*(1 - \beta)]\delta_m$ from the spot market at $C_m(t)$, and the remaining quantity $[D(t) - Q^*(1 - \beta)](1 - \delta_m)$ at Cf from the manufacturer under the QFC.

The retailer's differential profit gained under QFC compared to traditional contract $\Pi_R^{(QFC-TC)}(t)$, in Scenario 3, is computed at each t by (12) or (13), depending on the exercise of the option (OQFC = 1) or not (OQFC = 0) respectively.

$$\Pi_R^{(QFC-TC)}(t) = -C_m(t)[D(t) - Q^*(1-\beta)]\delta_m - C_f[D(t) - Q^*(1-\beta)](1-\delta_m) - \{-C_T[D(t) - Q^*(1-\beta)] - P_{pm}[Q^* - D(t)]\} \quad if \;\; O_{QFC} = 1 \tag{12}$$

$$\Pi_R^{(QFC-TC)}(t) = -C_f[D(t) - Q^*(1-\beta)] - \{-C_T[D(t) - Q^*(1-\beta)] - P_{pm}[Q^* - D(t)]\} \quad if \;\; O_{QFC} = 0 \tag{13}$$

The retailer's differential profit gained under QFC compared to traditional contract over the total time horizon T, which depends on the length of the QFC, is computed as the sum of the discounted profits gained at each t (with t = 1, …, T), as in (14).

$$\Pi_R^{(QFC-TC)} = \sum_{t=1}^{T} \frac{\Pi_R^{(QFC-TC)}(t)}{(1+i_c)^t} \tag{14}$$

The manufacturer's profit in the traditional contract Π_M^{TC} is computed, for the Scenario 3, by equation (15).

$$\Pi_M^{TC}(t) = C_T\big(D(t) - Q^*(1-\beta)\big) + P_{pm}\big(Q^* - D(t)\big) \tag{15}$$

The differential profit that the manufacturer gains under QFC compared to the traditional contract, in Scenario 3, is affected by the retailer's decision to exercise the option and the availability of the spot market to provide the required quantity. When the retailer exercises the option, the manufacturer's differential profit decreases since the quantity sold to the retailer decreases to $(1-\delta_m)[D(t) - Q^*(1-\beta)]$. When the retailer does not exercise the option, the manufacturer gains a higher differential profit which is the difference between its revenues $C_f[D(t) - Q^*(1-\beta)]$) and its production costs $\left(C_p[D(t) - Q^*(1-\beta)] + C_c^{QFC}\right)$. The differential profit of the manufacturer in scenario 3 under QFC compared to the traditional contract $\Pi_M^{(QFC-TC)}(t)$ is computed, at each t, by (16) or (17), depending on the exercise of the option by the retailer (OQFC = 1) or not (OQFC = 0) respectively.

$$\Pi_M^{(QFC-TC)}(t) = C_f[D(t) - Q^*(1-\beta)](1-\delta_m) - C_p[D(t) - Q^*(1-\beta)](1-\delta_m) - C_c^{QFC} - [(C_T - C_p)[D(t) - Q^*(1-\beta)] + P_{pm}(Q^* - D(t)) - C_c^{TC}] \quad if \;\; O_{QFC} = 1 \tag{16}$$

$$\Pi_M^{(QFC-TC)}(t) = C_f[D(t) - Q^*(1-\beta)] - C_c^{QFC} - [C_T[D(t) - Q^*(1-\beta)] + P_{pm}(Q^* - D(t)) - C_c^{TC}] \quad if \;\; O_{QFC} = 0 \tag{17}$$

The manufacture's differential profit gained under QFC compared to traditional contract over the total time horizon T, which depends on the length of the QFC, in Scenario 3, is computed as the sum of the discounted profits gained at each t (with t = 1, …, T), as in (18).

$$\Pi_M^{(QFC-TC)} = \sum_{t=1}^{T} \frac{\Pi_M^{(QFC-TC)}(t)}{(1+i_c)^t} \tag{18}$$

3. EXPERIEMENTS AND ANALYSIS

The proposed model's application has been illustrated by considering a SC coordination problem handled through QFC from an example company that is effectively similar to the real-world business unit of a company operating as retailer in a European country where one of the authors was involved in supply chain management for several years.

Once the base-line model was tested, we carried out a simulation analysis to investigate the effect that contract terms and implementation conditions have on the differential profits of both actors and on the entire system.

We designed a plan of experiments consisting of four experimental settings (in total 30 scenarios), which are briefly described in the following. The first experimental setting aims at investigating the effect of flexibility (α and β) on QFC effectiveness in coordinating SC under demand and spot price uncertainty. The second experimental setting aims at investigating the effect of the availability of the spot supply market to provide the quantity required by the retailer (λ) on QFC effectiveness in coordinating SC under demand and spot price uncertainty. The third experimental setting aims at investigating the effect of contractual duration (T) on QFC effectiveness in coordinating SC under demand and spot price uncertainty. The fourth experimental setting aims at investigating the effect of higher bargaining power of one actor (manufacturer) on the other (retailer) (Cf >> CT) on QFC effectiveness in coordinating SC under demand and spot price uncertainty.

4. CONCLUSIONS

A simulation-based research has been carried out in order to analyze the effectiveness of QFC as SC coordination mechanism under market demand and spot market uncertainty, by measuring such effectiveness in terms of the profits gained by each actor under QF contract with respect to the profits obtained under traditional contracts. In so doing and by varying the contract terms and implementation conditions we ensure that the QF is chosen only when it ensure a win-win condition, namely it improves the profits of both parties.

The experiments show the effect that contract terms and implementation conditions have on the benefits of both actors and on the entire system thus providing guidelines to the contract design in order to ensure that higher profits are attained for both parties (win-win situation).

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A LOGISTICS CENTER ORDER PICKING METHOD

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Abstract

The purpose of this paper is to develop a generic strategy for improving the efficiency of picking customer orders and replenishment relocation termed, a logistics center order picking and replenishment method (LCOPRM). The LCOPRM was tested in a large-scale logistics center for an office equipment retail company. The results show that by implementing the LCOPRM, the picking route for 51% of customer orders was minimized by 50%, the picking route for the other 49% of customer orders remained unchanged and the number of replenishment tasks was reduced by 38.75%.

Keywords: *logistics center, order picking, design and planning, interior design, case studies*

1. INTRODUCTION

In the face of increasing international production and trade globalization, logistics centers are fast becoming central to the efficiency of retail supply chain management [1]. A logistics center is a specific area where all the activities relating to transport, logistics and goods distribution are performed by various operators and tools. Dedicating specific areas to these activities implies planning the space and rationalizing infrastructures to optimize area utilization [2]. The warehouse of a typical logistics center consists of the following areas: distribution, offices, reception, picking and packaging. Usually, in practice, the interior design of the picking area is divided into two zones: a long-term storage zone and short-term storage zone that serves as the picking location. The flow of items or stock keeping units (SKUs) throughout the warehouse passes through the following process: receiving, storage, order picking and distribution [3]. Order picking involves assigning inventory to order lines, releasing orders to the floor, picking the items from storage locations, and the dispersion of the picked items [4]. The main activities of a logistics center are: (1) receiving materials from suppliers and storing the materials in the long-term storing zone, (2) preparing orders from external and internal customers for picking, (3) picking, routing and packaging customer orders, (4) locations replenishment, i.e., moving items from the long-term storage to the short-term zone for future picking, and (5) distribution of the orders to the appropriate customers. Among logistics center operations, order picking, and replenishment have been reported to be two of the most labor-intensive activities. Inefficient picking and replenishment processes can be a source of significant waste. This paper presents a generic strategy for eliminating waste by improving the efficiency of these activities using a logistics center order picking and replenishment method (LCOPRM). Improving order picking efficiency generally means minimizing the total order picking time. This includes the travel time incurred in picking an order which corresponds to the length of a picking tour from start to finish [5]. Improving the replenishment activity usually means reducing the number of storage refreshing tasks.

Determining the proper storage locations for potentially thousands of products is one major task. One of the main factors that affect the storage assignment is the order picking method. Chan and Chan [6] present a simulation study of a real case regarding the storage assignment of a manual-pick and multi-level rack warehouse. They concluded that the key to effective implementation of a storage assignment system is to match the type of warehouse storage system to the variety of items in the customer order. Also, the use of key performance indicators should clearly reflect the needs of the warehouse. Strack and Pochetand [7] propose a tactical model that did not include the order picking activity for the warehouse management system (WMS) which integrates several phases of the decision process: replenishment, allocation of products and assignment of products to storage locations. Jinxiang et al. [8] offer a detailed survey of the research on warehouse design, performance evaluation, practical case studies, and computational support tools. They suggest that avenues for important contributions for future research include studies describing validated or applied design models, and practical case studies that demonstrate the potential benefits of applying academic research results to real problems. The LCOPRM presented in this paper intends to fulfill these latter suggestions.

Based on a real problem, this study presents an applied design model illustrated by a practical case study. A case study is a linear and iterative process that includes the following stages: plan, design, prepare, collect, analyze and share [9]. We acknowledge that, on one hand, the case study method lacks quantitative rigor which makes it difficult to replicate results. However, on the other hand, we concur with Rowley [10] that the large amount of data accrued from case study research enables a certain amount of generalization to emerge. The authors believe that the experience from case studies performed in the industry provides proof of concept, demonstrating the successful application of such academic research results to real problems.

Large-scale logistics centers usually use a WMS to manage all relevant information. The WMS is used to track inventory, receive and place items in complex automated storage, and retrieve items by order pickers [11]. The WMS thus produces a large amount of historical data on customer orders that can be retrieved, reclaimed, analyzed, and presented to manufacturing decision makers [12]. A customer's order may consist of one or more items, each with a different requirement. While fulfilling the customer's order, sometimes a warehouse splits the customer order into smaller pick lists (e.g., a list of separate items for picking, each with different quantities). Each pick list is handed out to an order picker. The order picker goes to the relevant locations in the warehouse to pick the correct quantity of each article using material handling equipment, such as a forklift. Wave picking or batch picking [5] enables customer orders to be picked simultaneously by a group of order pickers [13]. Usually, a single customer order is attached to a specific order wave which handles several customer orders and the route is given to the order picker using a pick list [14]. A pick list that minimizes order picking time is used for optimum planning. Several time-efficient heuristic methods to determine the route order in a single-block warehouse have been proven effective [4]: (1) S-shape method – if there is at least one pick in the aisle the picker will enter and cross the aisle in the block. (2) Return method – pickers enter and leave each aisle from the same entrance. Notice that in methods (1) and (2) aisles without picks are not entered. (3) Midpoint method – divides all the aisles into two areas; each area is routed by the return method. (4) Largest gap method – if the gap between adjacent picks is large, the picker performs a return route from both ends of the aisle. (5) Combined method – aisles with picks are either entered and crossed or entered and exited at the same point.

This paper presents a monolithic model for improving picking orders and replenishment activities in a large-scale logistics center for an office equipment retail company. The company logistics center covers 11,000 square meters and employs over 200 employees. There are over 4,000 items stored at 4,800 separate picking locations throughout the warehouse. The order is not split into smaller pick lists. Instead, each picker collects several orders related to a specific picking wave. The company warehouse is divided into two blocks. The picker's route begins at the front of one block of the warehouse and goes to the back using the S-shape method; the order picker then returns through the other block from the back to the front using the same method. The left block contains six rows, and the right block contains seven rows. There is also one single long row at the rear of the warehouse. The aisle width between two adjacent rows allows two forklifts to work simultaneously. There are several types of storage spaces in the warehouse, each with different dimensions: (a) "Varitz" – the smallest rack in the warehouse measuring 50 × 40 × 50 [cm^3] length × width × height respectively can contain several packages or a few units of a specific item; (b) "Rack" – measuring 100 × 60 × 100 [cm^3] can contain several boxes; (c) "Flow Rack" – has a sloping shelf with wheels measuring 240 × 40 × 50 [cm^3] and can contain several boxes; (d) "Small" – can contain half a pallet and measures 120 × 80 × 100 [cm^3]; (e) "FullPlt" – measuring 120 × 80 × 200 [cm^3] can contain up to one pallet; (f) "Double Deep" (DD) – measuring 240 × 80 × 200 [cm^3] can contain up to two pallets. The long row at the rear of the warehouse is of type DD only. As part of its policy to adopt a lean management methodology and to strive for continual improvement of the logistic process [15], the company acquired a WMS called "Warehouse Expert" which is the flagship product in Made4Net's company supply chain suite. Recently the office equipment retail company also built an advanced warehouse with new equipment and technologies. Despite these improvements manpower costs remained unchanged (mainly due to the employment of workers in multiple shifts). The value stream mapping (VSM) tool [16] helped to identify where to increase cost reduction efforts throughout the logistics center (i.e., by targeting the main sources of waste). In the current state, the picker passes through all the aisles to pick one order. Also, in many cases items are stored in inappropriate locations. For instance, an item with a high sales volume per month was in a small location type, which requires many replenishment tasks. By identifying the sources of waste in the warehouse the next stage is to suggest ways to reduce picking distances and the number of replenishment tasks. The remainder of this paper is organized as follows. Section 2 presents the LCOPRM that improves the performance of the replenishment and order picking activities. This section also provides an analysis of the process data and the implementation results. Section 3 summarizes the findings and suggests some future directions.

2. THE LCOPRM POLICY

The focus of the current research is to develop a method for performing order picking and replenishment activities. Our method uses the class-based storage (CBS) policy. Whereas in the literature the outcomes of using this policy have been shown by simulation only (see [17-19]), in this study the results are illustrated by the problem solved in a real logistics center. Prior literature discusses many different methods for assigning products to shelf spaces to optimize order picking such as the cube-per-order index [5] or storage assignment based on item demand correlation [20]. The LCOPRM developed in this research is divided into five stages (see Figure 1). The first stage of the method uses the ABC method, a special case of the CBS policy [21]. It analyzes warehouse processing data and classifies items according to their relative number of picking tasks into three groups, A, B, and C. The Pareto principle on which the ABC method is based, states that 80% of the number of picking tasks comes from 20% of the items [22]. The second stage uses a heuristic to define the best location type in the warehouse for each item, considering the item's sales volume. The third stage includes selecting the best alternative for dividing the warehouse into areas, and the fourth stage selects a route strategy for the pickers. The final stage includes implementing the previous stages and measuring the difference from the current state. From time to time the logistics center practitioners should return to the first stage.

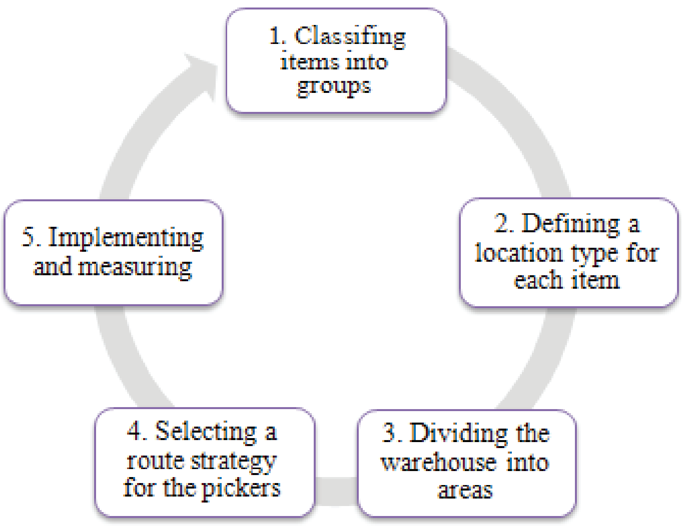

Figure 1 – A LCOPRM

2.1 Classifying items

In this paper the ABC method presupposes that the causes of waste are the items, and the effects are the number of picking activities such that: 20% of the causes are responsible for 80% of the effects, 30% of the causes are responsible for 15% of the effects, and 50% of the causes are responsible for 5% of the effects [21]. During the study, the items and the picking activities were classified using the same policy. Since items of category A (which are the most common in the collection of orders) were scattered throughout the warehouse area, the picker had to travel a long distance to complete a single picking wave.

To examine the categories of items (A, B or C) in an average customer order, the orders and their waves during an ordinary work day were checked. The purpose was to see if a pattern repeats itself in each wave. 24 different waves on different dates were examined. Each wave contained an average of 296 orders and 1,261 different items (totaling 30,264 items). Each order had an average of 4.4 items and the picker had to pass through an average of 10.3 rows per wave. With a confidence level of 95%, the distribution of the customer orders in each wave contained the following averages: 39.2% orders with only A-category items, 11.%^ with only C-category items, and 49% with items from two or three categories. To reduce the distance needed to travel per wave, the authors recommended grouping all items of category A together in one area, and all items of category C in another area of the warehouse (leaving all items of category B in yet another area).

2.2 A Heuristic to find a picking location for each item

Every item in the warehouse has a unique picking location. The responsibilities of the replenishment department are: (1) Selecting the proper location for each item according to demand. As demand for an item increases or decreases, an appropriate picking location is selected according to its sales volume; and (2) ensuring that the inventory at each picking location is sufficient for the next wave. Usually, this means moving items from the long-term storage zone to the picking locations.

Prior to the current research, there was no organized method for determining the locations of items. Placement was based solely on the experience and logic of the employees in the replenishment department. In this study, a heuristic approach is proposed to set a location type for each item to minimize the number of replenishment tasks. Due to the warehouse capacity limitations, some of the items would be stored in a location type that can contain up to four weeks of demand. Let X_n $\forall n = 1 \dots 6$ represent the capacity of location type n (i.e., the location volume in $[cm]^3$), such that for n equals to: 1 = Varitz, 2 = Rack, 3 = FR, 4 = Small, 5 = FullPlt and 6 = DD. Let j = 2,3 or 4 weeks and represent the amount of inventory periods in weeks. Let $Y_j = 4/j$, be the inventory turnover (i.e., number of replenishment tasks) per month, such that: $Y_2 = 4/2 = 2$, $Y_3 = 4/3 = 1.25$ and $Y_4 = 4/4 = 1$. Also, let Z_i be the sales volume of item i per month in $[cm]^3$. For instance, if the average month sale quantity of an eraser is 200 units per month and the dimensions of one unit is $4.3 \times 1.9 \times 1.3$ $[cm^3]$, then the eraser sales volume, $Z_i = 4.3 \times 1.9 \times 1.3 \times 200 = 2{,}124$ $[cm]^3$/month. The heuristic is divided into two phases: (1) calculating for item i and inventory period j the appropriate picking location type (denoted by x_{ij}), and (2) selecting for item i the best location type, out of the options given in phase 1. In phase 2, a location type is selected for each item out of the options given in phase 1 to fully utilize the picking locations in the warehouse. Since the problem is constrained by a predefined number of locations of each volume type, it belongs to the family of Knapsack problems [23]. Previously, it was decided that all items of each category (A, B and C) would be located together in the same warehouse area. Hence, to simplify the Knapsack problem at hand, the number of combinations was reduced from $4{,}000^3$ to 3^3 by selecting an inventory turnover (i.e., inventory periods in weeks) for each category of items rather than for each individual item. The inventory period (in weeks) per category is presented by: (1) the total number of replenishment tasks per month, and (2) the utilization of the picking locations in the warehouse. The utilization percentage of the location types is calculated as $\sum_i X_{xij}$ divided by the total volume of the locations in the warehouse. The number of replenishment tasks per month is calculated as $\sum_i (Z_i / X_{xij})$. The utilization should be less or equal to 100%. If this is not the case, the combination is denoted as unfeasible, and the number of replenishment tasks should not be calculated. Note that, the combination that achieves the minimal number of replenishment tasks per month is choosing inventory period three, two and four weeks for categories A, B, and C respectively. Based on the results of phase 2 one can choose a location type for each item according to its category and the calculation performed in phase 1. The item with an SKU = 1112354, for instance, will be in location type DD, since the inventory period for items of type A is three weeks.

2.3 Dividing the warehouse into three areas

The third stage of the LCOPRM requires dividing the warehouse into three areas and implementing a picking route strategy. Many alternatives for dividing the warehouse into three Pareto areas were examined. Each alternative must meet the following principles of the company: (a) for picking simplification each aisle must contain only one location type, and every area must contain all the location types; (b) minimize traffic jams in the warehouse (i.e., one forklift should not block the passage of another forklift). Note that as the area contains longer aisles (i.e., more than one block), the probability of traffic jams increases; and (c) the last long row at the rear of the warehouse must belong to items of category A, since many of these items require the DD location type. Out of multiple options that can be considered for dividing the warehouse into three areas, the four most practical options for the company under study are presented in Figure 2. All options satisfy principle (c). Options 1 and 4 do not satisfy principles (b) and (a). According to factory data, option 2 does not satisfy principle (a). Therefore, option number 3 is preferred, since it satisfies all the company's constraints.

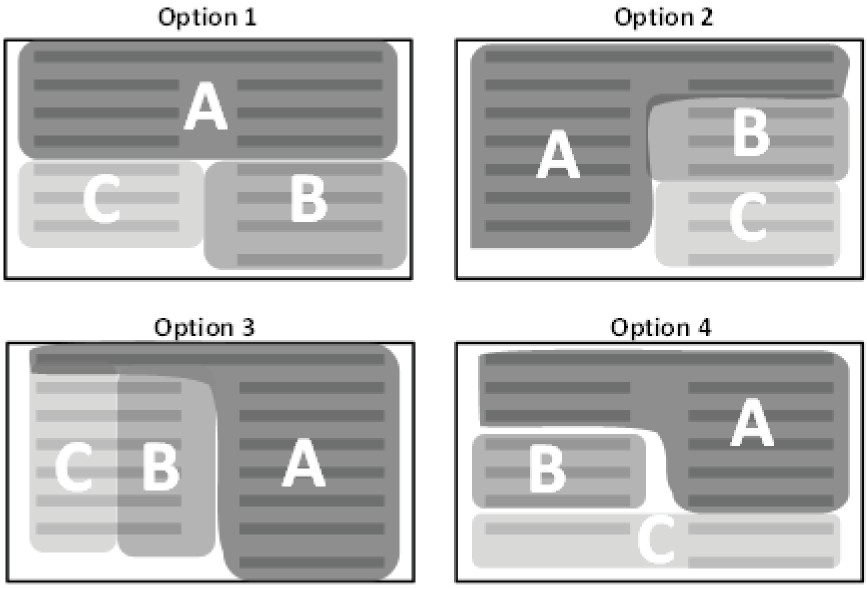

Figure 2 – Pareto alternatives

2.4 Selecting a route strategy for the pickers

In the fourth stage the route strategy for the pickers is selected. The picking route strategy refers to the path that the pickers follow while collecting items. Each time a picker finishes collecting one order of a wave, the same picker starts a new order in the same wave. The picker receives a list of items from the WMS sorted according to the worker's route. The route begins from the starting point (noted as S in Figure 3) and ends at the finishing point (noted as F in Figure 3), moving from one aisle to the next. To determine the minimal route, one should consider that 39.2% of customer orders are only from category A, and 11.%٨ of the customer orders are only from category C. Therefore, for 51% of the orders the picking takes place on only one block of the warehouse and on two blocks for the other orders. Alternative 3 in Figure 3 describes a two or one S-shape (according to the order) and is the only one that enables picking from one block if needed.

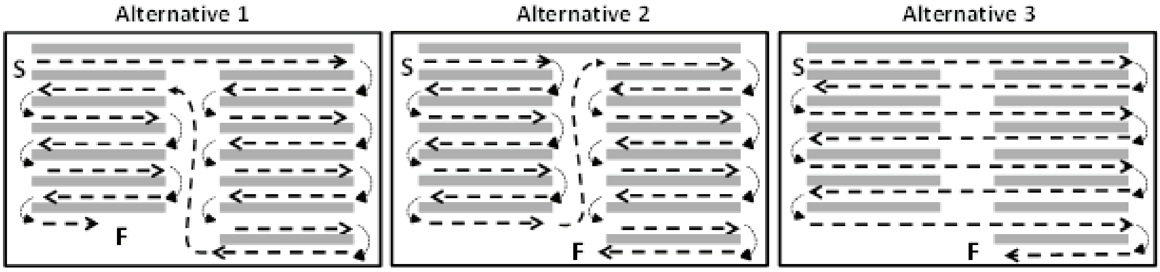

Figure 3 – Alternatives of picking route

2.5 Implementing and measuring

This section presents the implementation results of the stages described in Sections 2.1-2.4 (i.e., the fifth stage of the LCOPRM). The status of the warehouse before and after implementation of the new method is displayed using performance measures that include the distance a picker travels while picking a customer order and the average number of replenishment tasks per month. Before implementing the new method, the picker passed 15 aisles (seven on one block and eight on the other block) to pick a single order. After implementation, on average the picker passed through 0.392 × 9 + 0.118 × 7 + 0.49 × 15 = 11.7 aisles/orders, an improvement of 22%. At the initial state (period *a*) the average number of replenishment tasks per month was 4,853. After implementing the LCOPRM (period *b*), the average number of replenishment tasks per month was 2,964, an improvement of 38.747%. Sorting and placing items according to the ABC method required changes of the location types for many items and no change for others. The items were divided into three classes: (1) high demand items that were in a small location type and were therefore moved to a larger location type; (2) low demand items that were in a large location type and were therefore moved to a smaller location type; and (3) items whose demand corresponded with their location type and remained in place. Changes in the average item replenishment tasks per month were examined statistically (with $\alpha = 0.05$) before (μ_α) and after (μ_β) implementation of the new method by a paired sample t-test (F1). The null hypothesis states that there was no influence of the LCOPRM on the number of replenishment tasks per month (H_0), and the alternative hypothesis (H_1) states that μ_α and μ_β are not the same.

$$H_0: \mu_\alpha - \mu_\beta = 0 \qquad H_1: \mu_\alpha - \mu_\beta \neq 0 \qquad \text{(F1)}$$

3. SUMMARY

Order picking is typically one of the most time-consuming activities and a large contributor to operational costs in warehouses [24]. Clearly, improving order picking is an important way to save costs in logistics centers. Furthermore, because many customers tend to order late and expect quick delivery, warehouses must improve the efficiency of their order picking [25]. The LCOPRM proposed in this paper presents a practical approach that companies can implement swiftly. The method minimizes two major sources of waste in the warehouse: the number of replenishment tasks (a decrease of 38.747%), and the distance a picker travels while collecting customer orders (22% shorter). This is accomplished by selecting a suitable location type for each item according to its sales volume. Disregarding the correspondence between the item sale volume and its location type generates unnecessary work, excessive manpower, spending overtime, and failure to comply with customer service agreements. Also, the method proposed in this paper divides the warehouse picking area into smaller areas according to the Pareto principle and selects a route strategy for the pickers. Preserving separate areas assures the reduction of the route needed to collect customer orders. Further research may be conducted to find different combinations of approaches for each stage of the LCOPRM for different industries and illustrating results via case studies. Those case studies might form the basis for proper implementation of the LCOPRM by logistics centers professionals. Since the project is based on the CBS policy, and the volume sale of each item may change due to seasonal factors and product turnover, the classification of items to category may change over time. Therefore, to conserve the results of this work the authors recommend addressing this issue. Since the classification of thousands of items to their category types and the adjustment of items to their appropriate locations requires considerable work, this research suggests the development of a specific LCOPRM module for the company WMS. The module suggested must send an alert when an item is in an area that does not correspond with its current volume sale; the model must also recommend the transfer of the item to the appropriate area and location type in the warehouse.

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SUPPLIER PERFORMANCE INDICATORS APPLIED TO MICRO AND SMALL ENTERPRISES OPERATING IN AÇU PORT COMPLEX IN BRAZIL

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Abstract

This paper aims to present suppliers' performance indicators for micro and small enterprises participating in the Local Suppliers Development Project promoted by SEBRAE in Rio de Janeiro, Brazil. Through a bibliographical research based on select authors and models a set of 17 theoretical indicators was proposed. The indicators can benefit the companies participating in the project of Açu Port Complex in meeting expectations and demand of the large companies in the industrial area. The indicators presented in this paper intend to be a response to the difficulty of SMEs to increase their competitiveness.

Keywords: *supply chain management, customer Service, purchasing and procurement*

1. INTRODUCTION

The Industrial Complex of Açu Port is located in the north part of Rio de Janeiro state in Brazil following the concept of port-industry. It is the world largest offshore support base closer to the Campos Basin, which is Brazil's largest oil producer area. Açu Port complex owns a total area of 130 km² with 9 terminals divided into offshore and onshore areas. It has been in operation since 2014, and received more than USD 4 billion in investment, and has been contributing significantly to economy, employment and income generation for municipalities around the area as well the development of local enterprises. The complex concentrates businesses focused on cargoes handling, such as bulk, iron ore, oil and general cargo. Also, it has the capacity to receive the world largest container vessels and to provide areas for companies' installation [1, 2].

Despite the economic development and the benefits, there are difficulties for the enterprise's full operation, since large companies installed in the complex presented difficulties to find local suppliers capable to meet their demands. Therefore, in 2014, the Local Suppliers Development Program was promoted by SEBRAE (Brazilian Service for Support to Micro and Small Enterprises) aiming to foment actions to ensure the competitiveness of small enterprises located in the area to meet the requirements of large companies installed in Açu Port [2].

In suppliers' selection, the objective is to verify if a supplier meets the conditions established to act as a supplier, that is, the focus lies on their supply capacity [3]. The companies must monitor the performance of suppliers, and it is necessary to collect and analyze data that allow the continuous monitoring of their supply activities, in order to establish trends and identify the areas that require adjustments [4]. There are several ways companies can evaluate suppliers, such as costs, quality, punctuality, flexibility, productivity and facilities [5].

The supplier evaluation process is relevant since it precedes the supplier's qualification and it is at this stage that the supplier's performance is evaluated and classified. This information should serve as input to improve future supplies and provisions. As a result of supplier performance evaluation, performance indexes are emerging. The objective, however, is to monitor the performance evaluation results, presenting the results to suppliers so that, in case of low levels of performance, improvements in their products and processes could be promoted [5].

In order to develop actions compatible with the reality of companies in Açu Port area, and to provide satisfactory results for all parts involved, the authors understand that it is necessary to measure the results generated by small companies participating in the project, to the extent of identifying improvement points that can be developed and improved by the companies and ensure a greater participation of local suppliers in the chain.

In this scenario, this article aims to present a set of suppliers' performance indicators compatible with the reality of small companies participating in the Local Suppliers Development Project promoted by SEBRAE in Rio de Janeiro State. The methodology developed to reach the mentioned objective is composed by the bibliographic study of suppliers' performance indicators in order to set up, analyze and propose indicators that are compatible with the responsiveness of small companies participating in the project, in line with the expectations of the large companies in the whole chain.

2. SUPPLIERS' PERFORMANCE EVALUATION MODELS

Performance measurement systems are composed of internal and external performance measures. Internal performance measures focus on required customer service activities such as costs, customer service, productivity, management and assets, and quality. On the other hand, external performance measures are fundamental to monitor, understand and maintain a customer-focused perspective, and can be measured through customer perception and benchmarking [6].

Balanced Scorecard (BSC) is an approach that combines financial and non-financial metrics to provide more relevant information about an organization's activities. The BSC has introduced performance measurement systems that quantify intangible assets in order to develop a framework allowing strategies' definition that value the representativeness of both tangible and intangible assets. These performance measures are represented in BSC in four different perspectives: financial performance, customer relationships, internal process performance and organizational learning and growth [7, 8, 9].

Supply Chain Operations Reference (SCOR) serves as a guide to performance indicators and actions that address the performance of supply chain, involving cycle time metrics, costs, chain flexibility and reliability, and assets management. The processes interact with each other within the internal and external boundaries of the focal company. The performance or metrics section of SCOR focuses on understanding the outcomes of the supply chain, which include the relation of suppliers, as well can be used to describe supply chains that are very simple or very complex using a common set of definitions across disparate industries [10].

Table 1 presents a critical analysis found in the literature for Suppliers' Performance Evaluation Models, indicating the categories of indicators on which each model is based. The models of Bowersox and Closs, Kaplan and Norton and Supply Chain Council were selected for this research because they present different perspectives of performance indicators that can be applied in the context of supplier evaluation, which is the main object of this paper.

Table 1: Selected performance evaluation models

Source	Indicators	Main characteristics
[6]	indicators of outcome and diagnostic in categories, such as: quality/customer satisfaction; time; costs; and assets.	Performance analysis is divided between internal performance measures and external performance measures, basically done through customer perception and benchmarking.
[7, 8, 9]	indicators related to the following perspectives: financial, customers, internal processes and learning and organizational growth.	The performance measures of this model must be directly linked to the company's strategy. A small company for example has difficulties implementing the model, because in most cases, it does not have a clear definition of its mission, vision and strategic objectives.

[10]	indicators related to customers (reliability, responsibility and flexibility) and the company (costs and assets).	Composed of a guide of pre-established indicators, subdivided among 5 main criteria. In addition, the model does not include indicators related to demand management, product development and customer service.

[11] highlights the relevance of performance measures in achieving a structure of excellence in logistics through the model from [6] including the perspective from suppliers. BSC results has a great potential when their perspectives are really implemented in the organization processes and employees are involved, generating an improvement in the overall performance of the company [12], as well the logistics processes. Some benefits of the SCOR model are improvements in supply chain management practices, as well as communication across all operations, starting from standardized definitions and terminologies in addition to process modeling and activities optimized according to best practices [13].

3. METHOD

In this paper the methodological procedures firstly used to elaborate this research was comprised of a bibliographical review aiming to select authors and models related to the theme of suppliers' performance evaluation as presented in the previous section. Next, the method to set up the proposed indicators focusing on suppliers' performance is showed. Figure 1 indicates the steps taken by the authors to reach the main goal of this research.

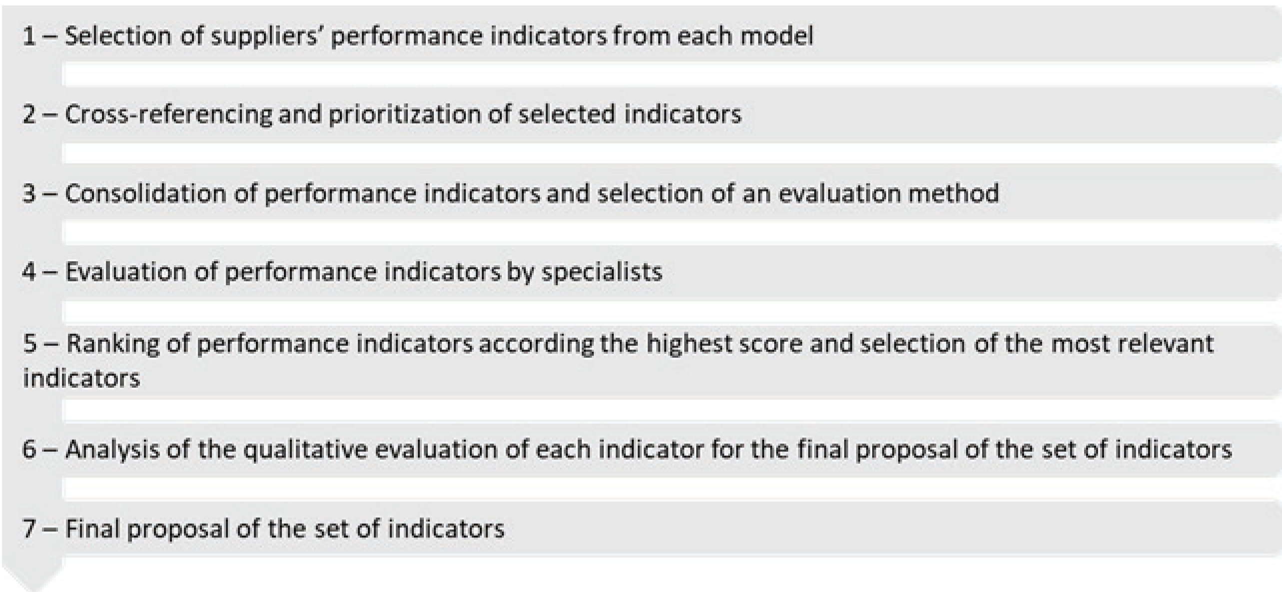

Figure 1 – Method for proposing the indicators

First a selection of suppliers' performance indicators was conducted based on the authors and models presented in the previous section. The first selection resulted in indicators that had similarities between the different models studied, so a cross-referencing of the indicators was made seeking a prioritization. At that stage, the objectivity and clarity of the indicators were taken into account to select the performance measures and it was also used the methodology proposed by [14]. The indicators then went through an analysis by specialists who have already participated in different Supplier Development Programs, and worked in suppliers' development actions within small companies. In this step, the specialists evaluated each indicator through a questionnaire using the Likert scale, where the parameters ranged from 0 to 5 in importance grade. Grade 5 signaled a high level of importance, but grade 1 signaled a low level. The performance indicators were ranked, and then, an analysis of the results from the specialists was carried out, in order to identify indicators of greater relevance, to evaluate the comments and suggestions for improvements, and finally to propose the set of indicators. The method used for this research will be better described in the next section.

4. PROPOSED INDICATORS

In order to present a set of suppliers' performance indicators compatible with the reality of small companies participating in the Local Suppliers Development Project promoted by SEBRAE in Rio de Janeiro State, the bibliographical analysis resulted in a first set of 79 metrics, related to each of the models presented above. Table 2 shows the previous search for the suppliers' performance indicators according to [6, 7, 8, 9, 10].

For the indicators' validation, a questionnaire was constructed with all the indicators resulting from the cross-referencing step and prioritization, that is, 48 indicators. This method was chosen because for this type of evaluation a quantitative research was necessary to prioritize the indicators with the highest score.

Table 2 – Indicators' survey

Model	Indicators' Category	Selection Criteria	Number of Indicators
SCOR	Reliability, responsiveness, flexibility, costs and efficiency in asset management	Maturity level of the companies from the Program led to the selection of levels 1 and 2 indicators and few of level 3	28
Balanced Scorecard	Internal and external perspectives: customer service, internal focus, costs, productivity and resource utilization	Indicators pointed out by [14] in a study applied in micro and small enterprises	37
Bowesox e Closs	Cost management, customer service, quality, productivity and asset management	Indicators found in literature, adapted from [15]	14
Total of Indicators			**79**

In order to select the performance measures, the methodology proposed by [14] was adapted to select metrics for this research, taking into account three pre-established evaluation criteria for each indicator, which are: relevance to the Supplier Development Program; facility of obtaining data for calculation; and easiness of understanding. In the questionnaire, there was also a field for comments for each indicator, so that the evaluator could leave its impressions and critics on each proposed indicator.

This questionnaire was applied to three consultants who have already worked in support actions for companies participating in the Supplier Development Programs promoted by SEBRAE. The consultants were chosen because of their experience in the subject. The questionnaires were presented face-to-face for each evaluator, aiming for the best understanding of the project objectives and the evaluation criteria of each indicator.

For a more careful analysis of the consolidated results, a weight was assigned to each of the evaluation criteria. For the criterion of relevance to the Supplier Development Program, the weight was assigned 3; facility of obtaining data for calculation was attributed weight 2; and easiness of understanding was attributed weight 1. The heavier weight for the Supplier Development Program criterion of relevance is in accordance with the main objective of this study, that is, to contribute effectively to the Program.

Following the specialists' evaluation, it was possible to notice that 19% of the indicators were categorized as highly relevant, 9 indicators. The specialists gave a higher score to indicators related to delivery quality, customers and documentation. On the other hand, 31% of the indicators evaluated by the specialists were considered of medium relevance and the rest of low relevance.

The general result of all indicators of high and medium relevance was analyzed for the final proposition of the performance indicators. Finally, 17 indicators are proposed for this study, subdivided in the following perspectives shown in Table 3.

Table 3 – Final Proposal of Suppliers' Performance Indicators

Perspective	Indicator's Proposition	Indicator's Purpose
Delivery quality	Performance of deliveries on the date promised to the client (%) = (Services performed on the promised date / total of services performed) * 100	Measure the % of deliveries made within the term agreed with the Customer.
	Customer complaints rate (%) = (Number of complaints about orders / total number of orders served in the period) * 100	Measure the % of complaints made on the executed order
	Customer satisfaction rate (%) = (Number of satisfied customers / Total number of clients) * 100	Measure the % of satisfied customers with the executed order
	Return rate / products devolution (%) = (Number of products returned and/or devolved / total number of products shipped in the period) * 100%	Measure the % of products returned over the number of products devolved because of vendor error
	Orders' conformity rate (%) = (Total orders in conformity / total orders) * 100	Measure the % of orders delivered on time negotiated with the Client, complete, without malfunctions and without problems in tax documentation
	Rework rate (%) = (Number of services remade / Total services provided) * 100	Measure the % of rework over services rendered
Comercial / documentation	Proposals conversion rate (%) = (Number of proposals accepted / Number of proposals sent) * 100	Measure the% conversion of proposals into contracts
	Total number of proposals = Total number of proposals submitted / Number of quotations received	Measure the number of proposals sent in a certain period of time
Clients	Capture rate of new customer (%) = (Total number of new customers / total number of customers) * 100	Measure the % of new customers the company manages to capture in a certain period of time
	Mean customer response time = (Total customer response time in counted days / number of replies sent)	Measure the mean time it takes to respond to the customer's request
	Client variation = Number of customers served in the previous measurement – number of customers served in the current measurement	Measure the range of customers served at each measurement
	Customer loyalty rate (%) = (Number of loyal customers / Number of total customers) * 100	Measure the % of loyal customers

Management	Productivity per employee = (Total units produced or sold / Total number of employees)	Measure the average of products sold or manufactured per employee
	Loss of stock (%) = (Number of defects in stock / Total number of units in stock) * 100	Measure the % of units lost in stock
	Demand forecast error rate (%) = (1 - (Planned units / Units shipped)) * 100	Measure the % error in the company's demand forecast
	Documentation delivery (%) = (Total documents delivered / Total documents requested for contracting)	Measure the % of documents delivered in bidding contracts
Financial	Cost deviation (%) = (Actual cost - Budgeted cost / Budgeted cost) * 100	Measure % of performance in cost planning. Lower the % better the performance

5. CONCLUSIONS

The main purpose of this paper was to present supplier's performance indicators according the scenario of micro and small enterprises participating in the Local Suppliers Development Project in Rio de Janeiro State. The set of suppliers' performance indicators presented in this research are theoretical and need more studies and valuation on their real applications and benefits for the companies participating in the project, as well meeting expectations of the large companies in the chain.

The indicators presented in this paper intend to be a response to the difficulty of small enterprises in the state of Rio de Janeiro to increase their ability to compete in diverse markets and meet different demands. In Brazil, small businesses in general face problems related to business management, strategic planning, data collection and information, innovation and competitiveness, and Rio de Janeiro companies are not different. For the performance indicators proposed in this paper meet their objectives, a process of sensitization and information management in the companies is necessary, mainly with the collaboration of the Supplier Development Program consultants. Typically, in consulting services that consist of information gathering and diagnosis of micro and small enterprises, it is observed a lack of systematic information, so it is necessary to work together with the consultant and the company to gather all the information needed and collect the proposed indicators.

Based on the proposition of the 17 indicators for suppliers' performance in this study and their application in companies participating in the project, it is expected for future researches the evaluation of the companies' capacity of response and, consequently, the analysis of the results to identify the current situation of the companies, as well identification and implementation of opportunities to improvement. In this way, this study is expected to contribute even more to increase the competitiveness of the small companies of the Program in order to meet the requirements of the large companies of the region, corroborating for the development of the chain as a whole.

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SUPPLY CHAIN MANAGEMENT IN THE TRAFFIC ENFORCEMENT CAMERAS SYSTEM

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Abstract

The Traffic Enforcement Cameras (TEC) system is a manufacturing system that produces traffic tickets as a service system for road user deterrence and prevention of traffic offences, which will lead to a reduction in the number and severity of road accidents. The TEC system consists of several working stations as a supply chain, therefore inventory and bottlenecks are part of the process. This paper presents an inventory management model based on a linear programming formulation. The results lead to a more efficient and effective system with higher and better quality production, low inventory levels and short lead time.

Keywords: *supply chain management, inventory management, customer service, operations management*

1. INTRODUCTION

Road accidents are one of the main problems associated with road transportation. Most road accidents occur as a result of human behavior; therefore police enforcement is one of the leading elements in helping to reduce road accidents using presence, conspicuousness, and enforcement, which leads to deterrence and prevention of offences. The traffic police's resources worldwide operate in a variety of methods as overt and undercover patrol vehicles, static or dynamic locations, and special equipment to enforce (i.e. alcohol, speed). One such equipment that many police forces and municipalities in several countries use is automatic traffic enforcement cameras, mainly for speeding and red light runners. These systems are efficient and effective for preventing offences and allowing the traffic police's resources to deal with other tasks with the limited budget constraints.

In Israel, the new digital Traffic Enforcement Cameras (TEC) system began operating in 2012 to enforce mainly speeders and red light runners. At the end of 2016 there were around 150 poles and 100 cameras spread throughout urban and interurban road sections and junctions. The system operates as a Public–Private Partnership (PPP) project according to a government resolution. The private company is responsible for establishing the system, and the different government ministries are responsible for handling the outcome as the life cycle of the traffic tickets with the police in charge of the entire project.

The TEC project is a manufacturing and service system. From the manufacturing aspect, it consists of several working stations at different stakeholders (private company, police, traffic court), as a supply chain that includes the flow of events (pictures of offending vehicles) into the police uncoding unit that produces traffic tickets from the events, and eventually payments for fines or at the court as a court sentence. Each station relies on other stations and it can operate as a push or pull system. As a manufacturing system the objective is to reduce bottlenecks, prevent a high level of inventory, and a high level of rejected items in the system. As a service system, the objective is to reduce lead time and increase quality tickets that maximally contribute to road accident prevention.

This study presents the TEC PPP project as a supply chain system. The flow and level of the raw materials in the project are determined according to a linear programming model that will be presented with the outcome. To the best of our knowledge, this is the first time a TEC PPP project is presented and operated as a supply chain system.

This paper is organized as follows: Section 2 is devoted to a literature review. Section 3 describes the TEC PPP process. Section 4 describes the data and the model. Section 5 presents the results. The final section summarizes the paper.

2. LITERATURE SURVEY

This is a multidisciplinary research, thus this section presents a brief overview of the relevant literature, including road safety and policing (section 2.1) and supply chain management (section 2.2).

2.1 Road safety and policing

On an annual basis, around 1.25 million people worldwide are killed as a result of road accidents. Road traffic fatalities were the 9th cause of death in the world in 2004 and it has been predicted to rise to 5th place by 2030. Road accidents are the leading cause of death in young people aged 15–29 and from a financial aspect, road traffic injuries are estimated to incur a global cost of US $518 billion, costing most countries 3%–5% of their gross national product [1, 2, 3].

An effective road safety strategy involves the classical 3Es concept: Engineering, Education and Enforcement [4]. The focus of this research is on enforcement of traffic laws, which has a direct impact on improving driver behavior and attitude and subsequently on reducing road accidents and casualties. Enforcement should focus on the main risk factors on the road: speeding, non-use of seat belts, drunk driving and mobile phone use while driving [5]. Here are some examples of quantitative measurements of the enforcement-behavior-road accidents relationship: Fell et al. (2014) discovered that a 10% increase in the DUI (driving under influence of alcohol or drugs) arrest rate is associated with a 1% reduction in the drinking driver crash rate [6]. Elvik (2013) describes the relationship between road accidents and speeding in his Power Model, which formulized the relationship between changes in the mean speed and changes in the number of road accidents and severity, by road type. For example, a 1% reduction in the mean speed will lead to a 4% decrease in the number of fatal road accidents and a 2% decrease in the number of all road accidents with injuries [7].

Traffic policing operates according to the road safety and criminology research areas. Traffic offenders will change their behavior if there is an optimal level of enforcement (based on minimum cost of apprehending and convicting traffic offenders), suitable punishment, and location according to hotspots analysis [8, 9].

Traffic police enforcement can be performed manually or automatically. The disadvantages of manual enforcement are mainly that it is time consuming and road users complain. In the current community-oriented policing, it is important to improve their relationships with the public [10] and to add technology to enforcement for cost effective enforcement on hotspots, which frees police officers to focus on other police tasks [11, 12].

The Automated Traffic Enforcement Cameras (TEC) detected speeders and red lights runners. For hotspots, this can be used to supplement traditional manual enforcement. Many studies found that using TEC reduces violations and reduces the number and severity of road accidents [13].

2.2 A supply chain management

The function of supply chain management (SCM) is to design and manage the processes, assets, and flow of material, information and finance between and among different companies to satisfy customers' demands with minimum cost [14]. A useful method to reduce cost is just-in-time (JIT) philosophy as a lean production with minimum inventories between the working stations. But JIT decreases the robustness of supply chains when it comes to disruptions, since a lean design, albeit it functions and performs well under normal circumstances, leaves little room for error when the situation changes dramatically [15]. Therefore, inventory control is the balance of the SCM. Inventory management keeps customers satisfied, inventory levels low, and operation costs to a minimum [16].

Today, the supply chain is not only a single manufacturing plant. It has been extended as supply chain collaborations or supply chain partnerships [17]. One example is the public-private partnerships (PPP) as a formal collaboration, generally for the long-term, between the public and private sectors, mainly for large infrastructure projects or services, where the set-up costs are heavy on the government's budget and the experts are in the private sector [18].

Most of the SCM models deal with manufacturing systems, but a few researchers are focusing on SCM for service systems (i.e. [19]) and even SCM in criminal law enforcement [20].

Here, the focus is on a TEC system, which is a manufacturing and service system, a PPP project as an infrastructure project and mainly a supply chain flow.

3. THE TRAFFIC ENFORCEMENT CAMERAS

The traffic enforcement cameras (TEC) system is described in section 3.1 and the process in section 3.2.

3.1. The traffic enforcement cameras system

In Israel, the digital Traffic Enforcement Cameras (TEC) project was established in 2012 as a government resolution. The project's goal is to reduce road accidents and casualties by reducing the number of speeding and red light offences using a combination of deterrence and enforcement processes. It is a joint project of several government ministries (Ministry of Public Security, Ministry of Transport and Road Safety, Ministry of Justice, Ministry of Finance), traffic courts, municipalities, private companies, government companies, and the Israel National Traffic Police, which is responsible for managing and operating this TEC PPP project.

The strategic plans of the project were to include 1,200 poles in rural and urban areas, in junctions and road sections, with 300 cameras moving between the poles. At the end of 2017 there were around 150 poles with 100 cameras. The fixed poles are located on the side of the road. They are a bright orange color and have a reflective strip (Figure 1(a)), a sign before (Figure 1(b)), and the locations are published on official websites (Figure 1(c)) and navigation applications. In addition, a public committee decided on the poles' locations based on road accident data analysis according to an economic cost-benefit analysis and the Power Model [7].

(a) A pole (b) A sign before the pole (c) The poles' locations (d) A site's structure

Figure 1 – Elements in the traffic enforcement cameras system

This type of camera detects a vehicle's speed using two sets of electronic detectors in the road surface, per lane. The system is activated when a car passes over the first detector. The speed is calculated by the time it takes the car to reach the second wire. If the vehicle's speed is higher than the pre-set enforcement speed level, a digital picture of the vehicle is taken [21]. The cameras at intersections enforce red light offences as well**.** The red light runners are detected if they cross the detectors when the traffic light is red (Figure 1(d)).

3.2. The traffic enforcement cameras process

The automatic traffic enforcement cameras project (TEC) is a Public–Private Partnership (PPP). The three main working stations in the process that are analyzed in this research are as follows: The process begins with the private company, which is in charge of producing the events (pictures + data) from the cameras and forwards them to the police uncoder unit as the second working station in the process. The uncoder police officer checks each event. If an offence is detected and the data is valid, a traffic ticket will be printed with the relevant data (i.e. the fine amount and the due date to pay, the court name and the court summons date) and sent to the owner of the vehicle or the offender by post. The traffic courts, which are geographically distributed, are the third and final working station in the process for the court summons.

As a supply chain, this process has inventory to manage. First is the event inventory that is waiting to be examined in the uncoder unit. Second are the court summons as a work in process that are the inventory for each of the traffic courts. The flow is controlled by the TEC flow model that is determined by the level of speed enforcement per site (described in section 4).

4. THE TRAFFIC ENFORCEMENT CAMERAS FLOW MODEL

Linear programming (LP) is a mathematical method to achieve the best outcome with linear relationships in the objective function and in the constraints. In our case study, the objective function is to achieve maximum benefit from the cameras' operations by determining the enforcement level per site per time with respect to all the constraints. This formulation describes the enforcement level determined by the police as a pull order from the private company and a push delivery to the traffic courts with minimal inventory for immediate deterrence according to criminology road safety aspects.

Several databases were used for the data: sensor data from the private company, ticket data from the different police units and the traffic courts [22].

The formulation is as follows:

Data: P - number of poles (p= 1,..,P); I - number of traffic courts (i=1,..,I); J - number of different types of punishments (j = 1,…J); K – types of speed enforcement levels (the speed limit above which offenders will get tickets) (k = 1,…K); W_0^E - The number of events as inventory in the uncoder unit at the beginning of the planning horizon; W_1^E - The number of events the uncoder unit can handle in the planning horizon; E - The maximum number of events as inventory at the uncoder unit at the end of the planning period; t_{pkj} - The expected number of tickets per punishment type j produced at pole p at speed enforcement level k during planning period (input from the sensors' data). a_{pkj} - The expected percentage of tickets per punishment type j produced at pole p at speed enforcement level k that go to court (the owner of the vehicle can ask for a court summons instead of a fine – input from the request unit database); $W_0^{TC_i}$ - The number of court summons as inventory in Traffic Court i at the beginning of the planning horizon; $W_1^{TC_i}$ - The maximum number of court summons that Traffic Court i can handle per planning period, i = 1,.., I ; TC_i - The maximum number of court summons as inventory at Traffic Court i at the end of the planning period; U_{pk}- The expected utility of the enforcement level k at pole p during the planning period (i.e. maximum reduction in road accidents according to Elvik's Power Model) [23].

Decision variables

$X_{pk} \in (0,1)\ \forall p, k$ defines the decision variable if a camera at pole p is operated at speed enforcement level k during the planning period.

The objective function:

$$max \sum_{pk} U_{pk}\, x_{pk}$$ Maximum Utility (The Power Model) (1)

The constraints:

$$W_0^E + \sum_{pkj} t_{pkj} x_{pk} - W_1^E \le E$$ Uncoder unit capacity (2)

$$W_0^{TC_i} + \sum_{\substack{pkj \\ p\in i}} a_{pkj} t_{pkj} x_{pk} - W_1^{TC_i} \le TC_i \quad \forall i$$ Court unit capacity (3)

The policy strives to maximize the utility from the TEC (Eq. 1) based on the Power Model [23], meaning that the operation where there are the maximum options to reduce road accidents and casualties by TECs (the objective function) is maximized according to the constraints and policy in the planning period: Eq. 2 describes the limitation constraint of the maximum number of tickets the uncoder unit can handle. Eq. 3 describes the limitation constraint of the maximum number of tickets, per court.

5. RESULTS

Supply chain management in the supply chain partnerships have resulted in the success of the PPP (Public–Private Partnership) TEC (Traffic Enforcement Cameras) project. The model went into operation in mid- 2014 and the speed enforcement levels per pole were adjusted according to the decision variables' results.

Figures 2 and 3 present the results of operating according to the model (section 4) to maximize the utility of the supply chain units with minimum inventories. Figure 2 presents the increase in the number of tickets and quality tickets. In 2015-2016, almost 130 thousand tickets were produced per year and the percentage of quality tickets rose to 22% in 2016. These numbers are the maximum tickets the uncoder unit and traffic courts can handle. Figure 3 presents the change in inventories: The blue graph in Figure 3 represents the average court summons inventory, meaning the average monthly gap between the court date and the offence date. It was reduced from 10 months in 2014 to 7 months in 2016, even though the number of court summons increased. The red graph in Figure 3 represents the change in percentages, with 2014 as the baseline year. In other words, the waiting time of the inventory event from the time it occurred to the time it became a ticket in the uncoder unit. In 2015 the time increased by 142%. This spike stems from the sharp increase in the number of tickets and the desire to minimize the inventory at the courts at the expense of inventory in uncoding. In 2016 both inventories were reduced.

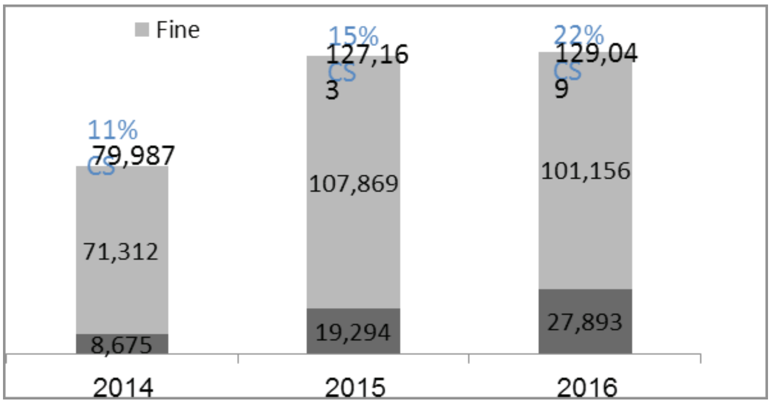

Figure 2 – The quantity of tickets by type

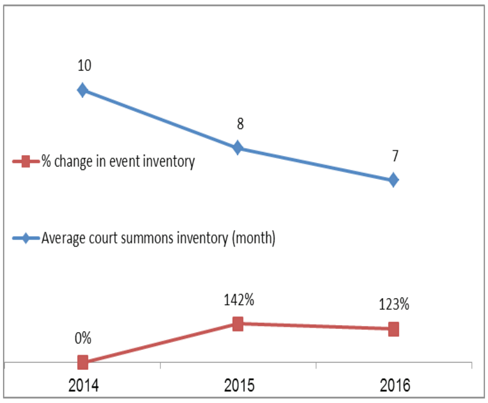

Figure 3 – The inventory level by type

6. SUMMARY

The Traffic Enforcement Cameras (TEC) project is a Public–Private Partnership (PPP). It is a supply chain partnership as a manufacturing and service system. Therefore, a supply chain management is required to achieve its goal of maximizing the utility from the TEC project based on the Power Model [23]. This paper presents an inventory management model based on a linear programming formulation. The results show a more efficient and effective system with higher and better quality production, low inventory levels, and short lead time.

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DETERMINING CRITICAL AIRCRAFT SPARE PARTS USING TEXT MINING AND ASSOCIATION RULE MINING TECHNIQUES

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Abstract

Determination of critical spare parts is a crucial task in aviation during the process of forecasting spare parts demand. It is also an extremely challenging task due to the fact that demand in the aviation industry is intermittent, i.e. it is small and highly variable in size. The aim of this paper is not to predict exact spare parts inventory levels by using traditional forecasting methods (e.g. Chroston's), but rather to discover critical spare parts during the low and high season. In order to succeed in that aim, text mining (TM) and association rule mining (ARM) techniques will be applied on a real-life dataset obtained from one European air carrier. Typical data mining steps; data familiarization, data pre-processing and transformation, model development and result interpretation, will be presented. Based on the insights obtained from the results, conclusions and guidelines for further research will be presented.

Keywords: *spare parts, aircraft, text mining, association rule mining*

1. INTRODUCTION

International Air Transport Association (IATA), in its exclusive benchmark analysis for flying year 2014, has indicated that airlines have spent $62.1 billion on maintenance, repair and overhaul (MRO), of which 40% was for engines, 22% for components, 21% for base maintenance and 17% for line maintenance [1]. The global MRO market is expected to grow by 4.1% per annum to $96B by 2025 [2]. In that share, there is a little change expected in relative mix of component and line MRO costs over the forecast period, i.e. it is expected that the component MRO costs will increase, while line costs will decrease [3].

In aviation, spare parts play an important role as they are highly correlated with the duration of the aircrafts' operational interruption. In other words, available spare parts ensure aircraft availability and decrease odds that the flight will be cancelled, delayed, or in the worst case – aircraft will be grounded. However, it is well known that the cost of the spare parts in aviation is extremely high and the market is limited. Each component of an aircraft must be certified by the airworthiness authorities, which define strict requirements to guarantee safety. Due to the high level of requirements to qualify a supplier, there is a very limited number of companies authorized to provide parts and services in the aviation industry [4]. More importantly, the investment in spares inventory ties up cash flow since these investments are often required before any revenue is generated. As a result, airline operators are less willing to stock and maintain large inventories of spare parts [5]. Furthermore, it is essential to note that demand in aviation is categorized as intermittent demand. In other words, spare parts in aviation often experience several periods of zero demand, and when demand occurs, it is small and highly variable in size [6].

Consequently, the importance of forecasting spare part demands has captured a lot of research interest in the aviation domain. More precisely, researchers have proposed approaches for forecasting spare parts using artificial intelligence methods [7], non-linear programming models [8], approaches based on combination of models (neural network, exponential smoothing and a grey model) [9], and independently developed methods [10]. Similar research studies, unrelated to aviation domain, also discuss approaches for erratic demand forecasting using adaptive autoregressive SVM model [11], traditional time-series method methods like moving average forecast [12] and exponential smoothing forecast [12, 13], Croston's forecasting method [12, 14, 15, 16] along with its modifications [12, 14, 17], and, among other, a fuzzy similarity based approach [18].

Although the literature presents a wide range of forecasting techniques for spare parts demand, airline operators usually base their predictions on operational experience [19]. In addition, as the demand for air transport varies with time, there are variations in daily, weekly and annual demand, leading to peaks at popular times [20]. This implies that experience of the company personnel is not enough to make accurate forecasts of spare part inventories. Therefore, it is important to draw objective decisions on the basis of which can be decided which spare parts should be stocked during this peaks.

Having in mind that one of the most valuable data sources in aviation are textual reports, a text mining should be performed in order to make use of this data and find critical components during the high and low flying season. By using text mining, a subjectivity can be avoided during demand forecast for spare parts because critical components are determined solely on the basis of patterns discovered within historical dataset. For that reason, a methodology for finding critical components within aircraft systems, based on the text mining and association rule mining, is proposed in this paper. A real-life data, obtained from a European airline operator, was used to test proposed methodology. Additionally, results were presented to maintenance experts and were confirmed as a valuable source of knowledge.

The remainder of this paper is organized as follows. Section 2 gives an overview of the text mining and association rule mining techniques. Section 3 presents the dataset obtained for this research. The methodology for determining critical spare parts is introduced in Section 4. Section 5 summarizes the text mining and association rule mining results. Finally, the conclusion of the research is presented in Section 6.

2. BACKGROUND

The main idea of the text mining is to isolate the terms which appear more frequently in unstructured textual records (documents) and use this knowledge in a decision-making process. The term-document is described by an N x p matrix Z, where N is the number of documents, and p is the number of keywords (features) in the union of all documents. A keyword is defined as a word that is informative about the content of the document. In order to remove terms from this matrix that have small frequencies as compared to the number of documents, it is customary to perform a data reduction technique known as Term Frequency Inverse Document Frequency (TF-IDF) to the term document matrix [21]. The TF-IDF reduction technique is composed by two measures. The TF measure computes the normalized term frequency, i.e. the number of times a word appears in a document, divided by the total number of words in that document. The second measure, i.e. IDF measure, is computed as the logarithm of the number of the documents in the corpus divided by the number of documents where the specific term appears [22].

Association rule analysis has emerged as a popular tool for mining commercial databases. The goal is to find joint values of the variables $X = (X_1, X_2,..., X_p)$ that appear most frequently in the database. It is most often applied to binary-valued data $X_j \in \{0, 1\}$, where it is referred to as "market basket" analysis. In this context the observations are sales transactions, such as those occurring at the checkout counter of a store. The variables represent all of the items sold in the store. For observation i, each variable X_j is assigned one of two values; $x_{ij} = 1$ if the jth item is purchased as part of the transaction, whereas $x_{ij} = 0$ if it was not purchased. Those variables that frequently have joint values of one represent items that are frequently purchased together [23]. Furthermore, association rules are created by analysing data for frequent if/then patterns and using the criteria *support* and *confidence* to identify the most important relationships. *Support* is an indication of how frequently the items appear in the database, while *confidence* indicates the number of times the if/then statements have been found to be true [24].

Before presenting a complete TM-ARM methodology, obtained dataset is presented in next section.

3. DATASET DESCRIPTION

The dataset contains information for approximately 1950 problems recorded by maintenance personnel from 20 January 2014 until 31 August 2017 for a small aircraft fleet which consists of 6 Airbus A319/20. For each problem, the date of the issue, aircraft registration, the category of operational interruption (delay, cancellation, flight diversions or aircraft on ground (AOG) status), ATA chapter (unique system code), textual description of the problem, and actions performed to resolve the problem were recorded. In order to find a critical system, distribution of the AOG records per system was analysed. In total, 85 reported problems per ATA chapters resulted in AOG status during the high and low flying season, as presented in Figure 1. The high season lasts from April until October, while the low season lasts from November until late March.

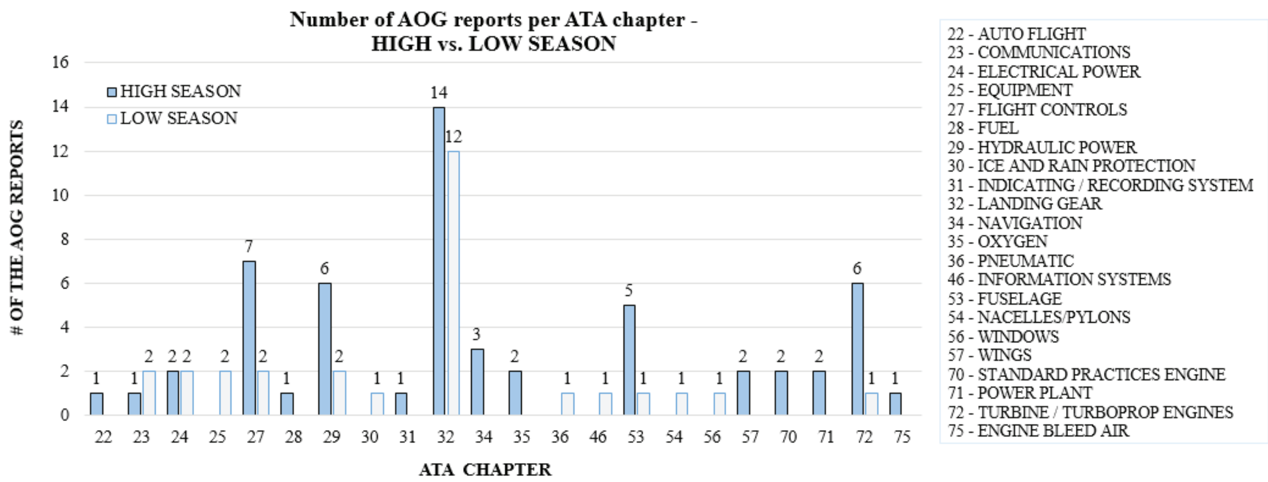

Figure 1 – Distribution of AOG records per aircaft systems during the high and low season

From Figure 1 it was noticed that during the observed period, the system with most recorded problems which resulted in AOG status was ATA 32 system (landing gear). Moreover, the distribution of recorded AOG failures during the high and low season for ATA 32 system was almost identical. Therefore, the data form this system were selected for further analysed. Additionally, a data pre-processing was conducted on original dataset. Once pre-processed, the data were suitable for modelling.

4. METHODOLOGY

In order to determine aircraft critical spare parts using text mining (TM) and association rule mining (ARM) techniques, a two-step methodology was developed. The methodology consists of the initial step, which includes data pre-processing activities, and a main step; model development step or the knowledge discovery step. Both steps were conducted using a RapidMiner platform.

4.1. Data pre-processing step

In the first step, a subset for further analysis was created. Since the records were logged by the Maintenance Control Centre (MCC) personnel, the original dataset was denoted as D_{MCC}. As mentioned in Section 3, the D_{MCC} dataset consists of attributes {*Date, A/C registration, Type_of_Operational_Interruption, ATA, Problem_descritpion, Actions*}. First, by using filtering operator in RapidMiner software, all records which did not belong to Airbus fleet (logged under *A/C registration* attribute) and which were not recorded for ATA 32 system (logged under *ATA* attribute) were removed. Hence, from original dataset, which contained around 1950 records, 259 records were kept and a new dataset, D_{MCC_32}, was created. Additionally, the records were further filtered by *Date* attribute, splitting the D_{MCC_32} dataset into two subsets; a D_{MCC_32H} subset, which contained 187 records logged during high season, and a D_{MCC_32L} subset, which contained 72 records logged during the low season. Finally, after filtering the records for specific aircraft type and system, attribute *Actions* was selected from both subsets before performing TM-ARM analysis. The reason for selecting only this attribute is because this attribute contains information regarding needed spare parts in order to resolve reported defect.

4.2. Model development step

Following the data pre-processing step, a TM-ARM process was built within RapidMiner platform.

By selecting the operator *Process Documents from Data*, which incorporated operators *Tokenize, Transform Cases, Filter Stopwords (English)*, *Filter Tokens (by Length)* and *Filter Stopwords (Dictionary)*, unstructured textual records were converted into word vectors, and a new datasets, $D_{MCC\_32H}{}^{T}$ and $D_{MCC\_32L}{}^{T}$, were created (Figure 2).

A TF-IDF measure was used for finding a frequent terms.

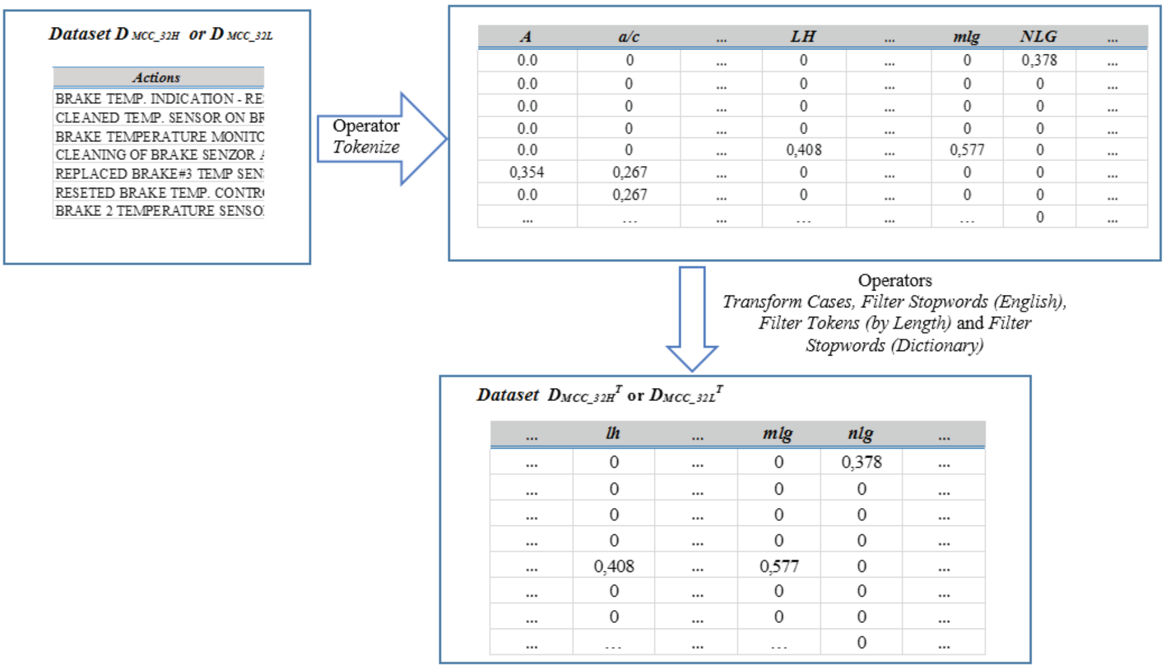

Figure 2 – A graphical explanantion of the TM part of process

From Figure 2, main functions of the RapidMiner operators can be distinguished.

By applying operator *Tokenize*, a tokenization, i.e. a process of extracting the text into terms, words, symbols or other significant elements called tokens, was conducted.

Transform Cases operator converts characters of all words (tokens) from upper case to lover case. The reason for using this operator was because in some records the same word was recorded in capital letters, and in some in small letters. Hence, this operator was crucial to avoid grouping the same terms that need to be turned into features.

Operator *Filter Stopwords (English)* was used for removing English stop words from documents, e.g. *a, the, an, and, or, nor, where,* etc. Similarly, operator *Filter Tokens (by Length)* was used for removing all the tokens with a minimum number of characters 2 and a maximum of 25, while operator *Filter Stopwords (Dictionary)* was used for removing all the tokens that do not contain valuable information (e.g. *ok, test, in accordance with, a/c,* etc.).

After applying all of the above mentioned operators, the result was a rank of the terms which occurred frequently within the datasets $D_{MCC\_32H}{}^{T}$ and $D_{MCC\_32L}{}^{T}$.

In addition, the association rules were found after applying the *FP-Growth* and *Create Association Rules* operators. A *minimum support* parameter was set to be 0.1 and a *minimum confidence* parameter to 0.6.

5. RESULTS

A TM-ARM process outcomes are presented in this section. First, the most frequent terms were analysed and the initial assumptions were derived from these terms. In the end, association rules were evaluated.

5.1. Text mining results

Figure 3 shows 10 most frequent terms that occurred in the $D_{MCC\_32H}{}^{T}$ and $D_{MCC\_32L}{}^{T}$ datasets.

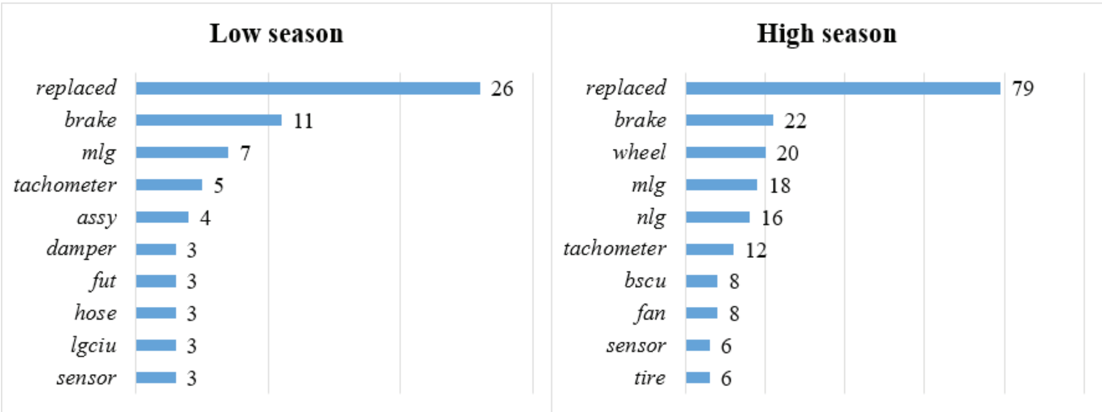

Figure 3 – Occurrences of the top 10 most frequent terms during the low and high season

By analysing terms presented in Figure 3, some hypothesis can be withdrawn. First, regardless of the season, it can be assumed that brakes will frequently cause problems on the ATA 32 system. Similarly, during both seasons, it can be assumed that replacement actions are more often associated with the components of the main landing gear (*mlg*). During the high season, components of the nose landing gear (*nlg*) also need to be replaced more often. It is evident that this components include wheels (or tires), dampers, brake fans, sensors, landing gear control and interface units (*lgcu*) and brake and steering control unit (*bscu*). Furthermore, it can be presumed that tachometer replacement are frequent during both seasons.

To confirm this assumptions, the association rules between the term *replacement* and other terms was discovered.

5.2. Association rule mining results

As mentioned previously, only terms that occur together in more than 10% of the records (*minimum support* parameter threshold), and whose combination is found in at least 60% of this records (*minimum confidence* parameter threshold), were selected to form the rules with the term *replacement.* The results are presented in Table 1.

Table 1 – Association rules for term “replacement” during the low and high season

LOW SEASON		HIGH SEASON	
$replacement		**$replacement**	
term 2	***confidence***	***term 2***	***confidence***
tachometer	1,000	brake	0,900
brake	0,727	wheel	0,833
sensor	0,667	tachometer	0,727
lgciu	0,667	sensor	0,667

Based on the rules presented in Table 3, all the assumptions made in Section 5.1 were confirmed by the maintenance experts. Additionally, the association rules were discovered for *mlg* term, and it was found that this term often appears together with terms *wheel* and *tire* due to the reported problems that the main landing gear tire is worn out and needs to be replaced. Observing at the *nlg* term, similar conclusions were made. This term was also related with terms *shock_absorber* and *sensor*, as the replacement actions on the nose landing gear often require replacement of the shock absorber seal and various sensors (e.g. proximity).

6. CONCLUSION

The main idea of this paper was to identify components that are main causes of the aircraft operational interruptions, and thus ensure that these components will be available on the stock. Hence, a methodology that combines the text mining and association rule mining analysis was presented for determining aircraft critical spare parts during the high and low season. For the case study, a real-life dataset, which contains information about problems that affected aircraft availability, was obtained. After performing an exploratory data analysis on the acquired dataset, it was found that the landing gear system (ATA 32) had most records which resulted in AOG status. Therefore, this system was selected for further analysis. Following the data exploration step, a TM-ARM process was developed using the RapidMiner platform. During the TM part of the process, a TF-IDF technique was selected for removing terms that were not informative about the content of the document, and a list of frequent terms was obtained. Subsequently, association rules were created and frequent if/then patterns were discovered after defining thresholds of *minimum support* and *minimum confidence* parameter. The results of the TM-ARM process have shown that, regardless of the season, almost the same components should be replaced for ATA 32 system. Considering the faultiness of these components and their consequences on aircraft availability, it is recommended that they are always in stock.

Obtained results were further analysed by aircraft maintenance engineers and were confirmed as a valuable source of knowledge for better spare parts management. This is mainly due to the fact that current way of determining stock levels is based on the spare parts list recommended by original equipment manufacturers (OEMs) or operational experience. Although the OEMs list takes into account the average failure characteristics of particular component, often does not reflect the real components’ replacement rate. Therefore, the TM-ARM analysis is more suitable for predicting inventory levers, as the results of this analysis are made upon actual dataset. Moreover, when observing economic aspect, implementation of this analysis can be completely free of charge for air carriers, as it can be performed using open source tools for data analysis.

To conclude, more detailed analysis can be performed by observing the component removal rate on monthly basis during each year. Also, it would be interesting to analyse exact historical demand records for the same period, and develop a predictive model for determining the spare parts stock levels.

7. ACKNOWLEDGEMENTS

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DISRUPTION MANAGEMENT – DEVELOPMENT AND EVALUTATION OF A MATURITY MODEL

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Abstract

High complexity in organization and technology together with the reduction of time and inventory buffers in the context of lean production increase the susceptibility of operational processes. As a result, process stability can no longer be guaranteed under economic aspects. The developed maturity model presents an analytical toolkit, which reflects the success factors of disruption management from the perspective of science and practice. Based on the maturity model, the status quo of disruption management is analyzed by a large-scale empirical study among German speaking companies.

Keywords: *disruption management, risk management, maturity model, supply chain management*

1. IMPORTANCE OF DISRUPTION MANAGEMENT

Disruptions in operational processes are one of the main problems in industrial companies and must be characterized as a cross-functional problem. Unexpected machine breakdowns, spontaneous changes in customer requirements, lack of care during working processes and especially unavailable materials and information refer to significant lacks between planned and actual processes. Empirical data and case studies show that disruptions often occur preferentially at the interfaces to external value creation partners. This proves the importance of disruption management especially for cross-company supply chains [1, 2, 3]. Despite the increasing relevance of this topic in complex supply chains, companies on each supply chain level are still disoriented to systematically deal with, analyze, and effectively handle unplanned events. Empirical studies show that the handling of disruptions is often uncoordinated and follows mainly unofficial processes. Company representatives describe appropriate measures as unpredictable and non-steerable due to high differences between single disruptions. In many cases, the responsiveness and duration to solve disruptions depend on the experience and knowledge of the employees concerned. In addition, in most cases there are no incentive systems for employees to act quickly and effectively in the event of a disruption. Disruption management enhances functional-specific and product-related processes with interdisciplinary strategies, measures and tasks as well as methodological knowledge and competencies required for reactive disruption handling and sustainable prevention of faults [4, 5].

Despite continuous process improvement programs, ensuring and guaranteeing process reliability in the event of a disruption is currently regarded only rudimentarily. An empirical study in the automotive industry from Czaja et al. shows that multiple disruptions and their consequences include great risks for all involved process partners within a supply chain [6]. Wünscher shows in company-internal analyzes that disruptions pose a high economic risk for companies and jeopardize the achievement of quality, cost and time targets. Resulting customer complaints can finally lead to reputational losses and image damages [7].

The developed maturity model in this article represents a currently unique analytical toolbox especially designed for disruption management. The model combines principles and design rules from process and lean management to reduce reaction times in the event of a disruption and to increase transparency of value added processes. On the one hand, the maturity model serves to capture the current development level in disruption management within German speaking companies. On the other hand, the model can be used to identify company-specific potentials to improve future processes. While the methods and ideas of lean management lead to a fundamental reduction of complexity of business processes, process management expertise helps to master the inevitable complexity of modern production systems. Using the model, selected criteria can be analyzed by skill levels to present companies an individual path to stable their processes.

2. DEVELOPING A MATURITY MODEL FOR DISRUPTION MANAGEMENT

The developed maturity model [8,9,10] identifies process or organizational problems in disruption management to find sustainable solutions to avoid corresponding future negative impacts. Disruption management is not a one-time action. When dealing with disruptions, a fundamental change in the organization of production systems is necessary. Processes, systems and qualifications of employees and managers have to be improved. Defining disruption management as an evolutionary development process, improvement measures can be realized in continuous steps. To create a holistic view, the maturity model uses a tripartite framework. The dimensions technical system, management infrastructure and attitudes and skills are cornerstones of transformation projects [11, 12, 13]:

► The technical system describes all activities, tools, materials, documents and information to carry out efficient value added processes. The identification of disruptions, for example, represents an essential phase in disruption management and is divided into the steps monitoring core processes, analyzing core process deviations and reporting malfunctions.

► Management infrastructure describes the organizational structure to control the technical system. These include, for example, the definition of strategies, guidelines and key figures as well as process roles and responsibilities. Stable structure and process organization increase the ability to react in the event of a malfunction and prevent long-term disruptions.

► Attitude and skills of employees and managers are divided in two parts. On the one hand, it considers personal feelings, mindsets, and opinions. On the other hand, technical knowledge, skills, qualifications and experiences are analyzed. The participation of employees in process stabilization projects is important to implement sustainable disruption management. Therefore, employees and managers must be encouraged to communicate and treat disruptions openly.

The identification of indicators for each dimension follows a scientific approach (keyword analysis in academic literature and databases [14, 15, 16, 17]) and is not limited to the current state of research. It includes also insights from different companies, which are determined by expert interviews. Altogether, the maturity model includes 33 indicators separated on all three dimensions (twelve indicators for the technical system, 13 for management infrastructure and eight for attitude and skills). All indicators are presented as part of the empirical validation in chapter five. The evaluation of the indicators follows Kahn et al. using a four-level maturity scale [18]:

► Maturity level 1 (very low): Incomplete – disruption management is hardly noticed and is still at the beginning.

► Maturity level 2 (low): Established – disruption management is perceived in its core function and is under continuous growth.

► Maturity level 3 (high): Integrated – disruption management is practiced and accepted by the majority of employees and managers.

► Maturity level 4 (very high): Excellent – disruption management is an integral part of the company and has high priority on top management level.

Despite the practical relevance of this topic, disruption management is quite less analyzed than related research fields as risk or quality management. There is no further maturity model that comprehensively addresses the problem of disruption management. Therefore, the results of the literature analysis are extended by success factors from company's perspective. In total, representatives from ten companies in different industries challenged the maturity model.

3. METHODOLOGY OF THE EMPIRICAL STUDY

3.1 Data collection

In a second step, the maturity model is used as basis for a large-scale empirical study focusing on the status quo of disruption management in German speaking companies. To gain most representative results, the survey was send to companies of different sectors and sizes. The participating companies are selected by the database "Top 500 companies in Germany 2016" of the journal DIE WELT [19].

In all cases, the participants (mainly executives in production, logistics, supply chain management or process improvement) received the questionnaire by email in form of a web-based document. Following a thematic introduction, the survey includes basic questions on disruption management and maturity-based components as the main part. Basic questions focus, for example, on success factors and objectives of disruption management. Overall, the questionnaire has 44 questions including all 33 maturity indicators. The maturity levels described in chapter two are used to assess the companies on a quartered (quasi)-interval scale.

The online survey was sent out between May and July 2017. Online surveys are temporally and spatially independent; therefore, it is suitable for larger and geographically widely distributed samples. In addition, they have a higher objectivity level compared to personal surveys. Especially the interviewer bias can be avoided. To prevent duplicate answering, repeated access to the survey page was technically excluded. After exclusion of incomplete answers, a total of 53 companies could be used as sample for the empirical analysis.

The problem of a "non-response bias" was taken into account, too. It can be assumed that especially companies that have already implemented disruption management were participating in the survey, while inexperienced companies can be expected to be represented to a lesser degree. However, this has no negative impact on the informational value of the study's results, since incentive management relevant topics are thus mostly discussed by companies who have already collected some experience in this area [20, 21].

3.2 Characteristics of the sample

Company representatives of various manufacturing industries as well as transportation/logistics and telecommunications, technology and electronics are surveyed in the empirical study. Table 1 shows the corresponding distribution of all participants. The percentage of industries is quite balanced with a small majority in the automotive and plant and mechanical engineering sector. Regarding the size of the companies (number of employees), the percentages are also very balanced with the exception of the category 5,000 to. 9,999 employees (3.8%). Overall, 79.3% of all participants are in leading positions as divisional or plant directors (28.3%) and general managing directors (22.6%). In total, the analyzed companies represent a meaningful random sample for the selected industries and the majority of executive participants ensure a high information value of the study.

Table 1 – Characteristics of the sample

Characteristics of the sample *(n=53; relative frequency)*

Business sectors of participating companies

Plant & mechanical engineering	Automotive	Aviation & aerospace	Health care, chemistry & pharma	Food & consumer goods	Telecomm., technology & electronics	Transport & logistics	Others
15.1%	18.9%	9.4%	9.4%	3.8%	9.4%	11.3%	22.7%

Position of participating persons

General management director	Divisional & plant director	Department manager	Team leader	Others
22.6%	32.1%	17%	7.6%	20.7%

Company size (employees)				
< 500	500-1,999	2,000-4,999	5,000-9,999	>10,000
24.5%	26.4%	20.8%	3.8%	24.5%

4. DISRUPTION MANAGEMENT – RELEVANCE, OBJECTIVES AND SUCCESS FACTORS

For most participating companies disruption management is an elementary competitive advantage in modern production systems. Currently, more than 75 percent of all companies describe the relevance of disruption management as high or even very high; the average value is 2.86 on a scale from 1 (very low) to 4 (very high). The future value is even higher with an average of 3.39. Almost 95% of all companies expect a high or even very high future relevance of disruption management (see table 2).

Table 2 – Relevance of disruption management

Relevance of disruption management (n=53; scale: 1 (very low) to 4 (very high))						
	Relative frequency of scale values				Descriptive statistics	
	1	2	3	4	Average	σ
Present value	6%	16%	64%	14%	2.86	0.96
Future value	3.8%	2.8%	44.4%	49.1%	3.39	0.89

Table 3 presents the main objectives of disruption management. Increased process transparency is the most important objective with an average value of 3.37. Increased learning ability of the system, quick resolution of and increased responsiveness to disruptions are also highlighted with values above 3 points. Costs reductions through reduced time and inventory buffers as well as a decrease of process complexity play only a minor role.

Table 3 – Objectives of disruption management

Objectives of disruption management (n=53; scale: 1 (very low relevance) to 4 (very high relevance))						
	Relative frequency of scale values				Descriptive statistics	
	1	2	3	4	Average	σ
Reduced time and inventory buffers	5.7%	35.9%	47.1%	11.3%	2.64	0.76
Increased learning ability of the system	0%	9.4%	54.7%	35.9%	3.26	0.64
Reduced process complexity	5.8%	23.1%	42.2%	28.9%	2.94	0.87
Increased process transparency	0%	13.5%	36.5%	50%	3.37	0.71
Quick resolution of disruptions	0%	13.5%	48.1%	38.4%	3.25	0.68
Increased responsiveness to disruptions	1.9%	11.3%	54.7%	32.1%	3.17	0.70

The definition of processes, key figures and standard regulations as well as top-management commitment are highlighted as most important success factors for disruption management with average values of 3.37 and 3.27 (see table 4). Integration (3.20) as well as training and education of employees (3.19) and the establishment of escalation levels (3.04) are also rated with high relevance. Overall, the focus is on standard procedures, education and participation of employees and executives. Technical aspects as the improvement of the technical system or the implementation of cross-functional coordination systems are rated quite lower instead. All relevant success factors are integrated in the following maturity model.

Table 4 – Success factors for disruption management

Success factors for disruption management (n=53; scale: 1 (very low relevance) to 4 (very high relevance))						
	Relative frequency of scale values				Descriptive statistics	
	1	2	3	4	Average	σ
Living failure culture	5.7%	24.5%	41.5%	28.3%	2.92	0.87
Integration of employees	3.9%	11.8%	45.1%	39.2%	3.20	0.80
Training and education of employees	1.9%	11.3%	52.8%	34%	3.19	0.71
Improvement of the technical system (e.g. hardware or software)	1.9%	30.8%	51.9%	15.4%	2.81	0.72
Implementation of cross-functional coordination systems	3.8%	39.6%	39.6%	17%	2.70	0.80
Establishment of escalation levels	3.9%	17.7%	49%	29.4%	3.04	o.80
Definition of processes, key figures and standard regulations for disruptions	0%	7.7%	48.1%	44.2%	3.37	0.63
Top-Management commitment	0%	7.7%	57.7%	34.6%	3.27	0.60

5. MATURITY LEVEL IN DISRUPTION MANAGEMENT

In all three main categories, the maturity level is consistent below three points, representing an overall rejection of a high maturity level. The category "attitude and skills" has the highest average value with 2.8 points, followed by "technical system" (2.7) and "management infrastructure" (2.4). Therefore, potentials for improvement can be found in all categories with the highest possibility in "attitude and skills".

5.1 Technical system

The technical system describes how plants and resources are used and optimized in the value added process to generate maximum value and minimize costs. It includes all activities, tools, materials, documents and information to carry out efficient processes. The maturity level in this category is developed by twelve indicators [22].

The determination of causes of process disruptions receives the highest average value with 3.34 points, whereas the elimination of identified causes is only rated with a maturity level of 2.95 points (see table 5). The companies have largely institutionalized the identification of causes, but continue to struggle to eliminate them in long term, which is also represented by the indicator sustainable problem solving with one of the lowest values (2.43). Monitoring of core processes (3.02) and reporting of process disruptions (3.02) are also indicated with a high maturity level, while the indicators performance measurement (2.23) and documentation and evaluation of disruption data (2.25) receive the lowest values. Therefore, one of the main challenges is to ensure a high level of transparency for disruption management using key figures and guarantee that the collected data is used purposefully to further develop the technical system. Another critical point is the determination of consequences of process disruptions (2.59), especially regarding affected customers. The implementation of a proactive warning system for affected customers is only rated with a weak level of 2.49 points.

Table 5 – Maturity level "technical system"

Maturity level (n=53; scale: 1 (very low) to 4 (very high))						
Indicators "technical system"	Relative frequency of scale values				Descriptive statistics	
	1	2	3	4	Average	σ
Monitoring of core processes	3.8%	13.2%	60.4%	22.6%	3.02	0.72
Analyzing deviations from core processes	0%	58.5%	32.1%	9.4%	2.51	0.67
Reporting of process disruptions	0%	39.6%	18.9%	41.5%	3.02	0.91
Reporting of detailed disruption data (e.g. disruption key)	1.9%	45.3%	26.4%	26.4%	2.77	0.87
Determining the causes of process disruptions	0%	11.3%	43.4%	45.3%	3.34	0.68
Eliminating the causes of process disruptions	1.9%	34%	32.1%	32.1%	2.94	0.86
Determining the consequences of process disruptions	11.3%	34%	39.6%	15.1%	2.58	0.89
Warning of affected customers	11.3%	43.4%	30.2%	15.1%	2.49	0.89
Documentation and evaluation of disruption data	13.2%	56.6%	22.6%	7.6%	2.25	0.78
Sustainable problem solving	9.4%	49.1%	30.2%	11.3%	2.43	0.82
Adapting core processes with increased susceptibility	5.7%	15.1%	60.4%	18.9%	2.92	0.76
Measuring the performance of disruption management	26.4%	34%	30.2%	9.4%	2.23	0.95
Total "technical system"	**--**	**--**	**--**	**--**	**2.71**	**0.58**

5.2 Management infrastructure

Management infrastructure describes the organizational structure to control the technical system. It includes, for example, the definition of strategies and guidelines as well as process roles and responsibilities. Flowcharts and organizational structures increase the ability to react in the event of disruptions and prevent long-term damages [23].

Management infrastructure receives the lowest maturity level of all categories with 2.4 points. The only indicator with a high average maturity level is expending employee powers regarding disruption management. 41.5% of all companies agree that employees are empowered to implement immediate measures and are allowed to make decisions independently. Transparency of necessary time slots between detection and solution of disruptions is the biggest problem in this category. The majority of all companies (54.7%) decline the existence of target values for the latent phase as well as the coordination, diagnosis and problem solving time. For the reporting time the corresponding percentage is 45.3%. Sustainable disruption management is also endangered by the fact that often no appropriate strategy exists and disruption management is not integrated in the corporate management system. This point is represented in the survey by an average value of only 2.23 points. Overall, the results show that a missing of standardization, transparency and communication rules can be highlighted as optimization potentials in the category management infrastructure (see table 6).

Table 6 – Maturity level "management infrastructure"

Maturity level (n=53; scale: 1 (very low) to 4 (very high))						
Indicators "management infrastructure"	Relative frequency of scale values				Descriptive statistics	
	1	2	3	4	μ	σ
Expending employee powers	3.8%	26.4%	28.3%	41.51%	3.08	0.92
Defining detectors and receivers of disruptions	1.9%	45.3%	43.4%	9.4%	2.60	0.69
Establishing a central point of contact for disruptions	22.6%	24.5%	22.6%	30.2%	2.60	1.15
Strategy development for disruption management	17%	34%	41.5%	7.6%	2.40	0.86
Establishing a standard process for disruption management	3.8%	26.4%	54.7%	15.1%	2.81	0.74
Recording and analyzing the latent phase between disruption detection and reporting	54.7%	5.7%	18.9%	20.8%	2.06	1.26
Recording and analyzing the reporting time	45.3%	13.2%	20.8%	20.8%	2.17	1.22
Recording and analyzing the coordination time	54.7%	7.6%	13.2%	24.5%	2.08	1.30
Recording and analyzing the diagnosis time	54.7%	5.7%	17%	22.6%	2.08	1.28
Recording and analyzing the problem solving time	54.7%	5.7%	13.2%	26.4%	2.11	1.33
Establishing a uniform disruption definition	24.5%	32.1%	22.6%	20.8%	2.40	1.08
Defining a standard process for disruption prioritization	3.8%	39.6%	39.6%	17%	2.70	0.80
Defining a standard process for disruption escalation	3.8%	45.3%	37.7%	13.2%	2.60	0.77
Total "management infrastructure"	**--**	**--**	**--**	**--**	**2.4**	**0.76**

5.3. Attitude and skills

The category attitude and skills contains two areas. On the one side, attitude considers the personal feelings, mindsets, and opinions of employees and managers. On the other side, technical knowledge, qualifications and experiences are summarized under skills.

Attitude and skills receives the highest maturity level of all categories with 2.8 points (see table 7). Nevertheless, even in this category, only one indicator, the existence of an open error culture (3.08), receives a high value above three points. 35.9% of all companies verify that employees recognize disruptions even as opportunities for positive change. Promoting quality awareness and management commitment receive values short below 3 points, which indicates also a quite high maturity level. Methods competences (2.59) have the lowest value, followed by social skills and knowledge exchange (each 2.59).

Table 7 – Maturity level “attitude and skills”

Maturity level (n=53; scale: 1 (very low) to 4 (very high))						
Indicators “attitude and skills”	Relative frequency of scale values				Descriptive statistics	
	1	2	3	4	μ	σ
Promoting quality awareness	1.9%	30.2%	39.6%	28.3%	2.94	0.82
Existence of an open error culture	1,9%	24.5%	37.7%	35.9%	3.08	0.83
Management commitment	1.9%	28.3%	45.3%	24.5%	2.92	0.78
Knowledge exchange regarding disruption management	0%	45.3%	50.9%	3.8%	2.59	0.57
Development of professional knowledge for disruption management	5.7%	15.1%	69.8%	9.4%	2.83	0.67
Development of methods competences	11.3%	32.1%	49.1%	7.6%	2.53	0.80
Development of social skills	5.7%	37.7%	49.1%	7.6%	2.59	0.72
Development of self-competences (e.g. personal responsibility, endurance)	1.9%	39.6%	52.8%	5.7%	2.62	0.63
Total “attitude and skills”	**--**	**--**	**--**	**--**	**2.8**	**0.49**

6. CONCLUSIONS AND FURTHER RESEARCH

The empirical results show that an increasing current and future awareness of disruption management is recognizable. Nevertheless, the implementation of an efficient disruption management is still not yet at a sufficient level. In all three categories technical system, management infrastructure and attitude and skills improvement potentials can be identified. The main challenges for companies are:

- Ensuring a sustainable problem solving process to eliminate root causes of process disruptions and avoid permanent fire-fighting activities.
- Establishing key figures for disruption management to ensure transparency of disruption data and to develop an analytical system to avoid or at least identify further disruptions at the earliest stage.
- Ensuring the determination of all consequences of process disruptions to identify interdependencies to other functional areas and identify all impacts on the company and affected external customers.
- Establishing an analytical tool kit to record and analyze the timeframe necessary to solve existing process disruptions including the setting of clear target values.
- Defining a long-term strategy for disruption management to ensure sustainable processes and organizational structures to avoid further negative impacts.
- Improving methods competences and social skills as well as establishing a holistic knowledge exchange system for all employees and managers.

Regarding the research framework, a limitation of the empirical approach might be the fact, that different kinds of industries are examined to get a general understanding of the topic. Therefore, further research should be focused on single industries to get a deeper insight into the specific conditions. In addition, it is to analyze whether there are national differences in a global context. Overall, this study can be used as a starting point for further research in disruption management, trying to reaffirm, reject or enhance our findings.

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PRINCIPLES OF SUSTAINABLE DEVELOPMENT IN MULTI-FAMILY HOUSING ESTATES

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Abstract

In 1989 in Poland, a political transformation, followed by great social and economic changes, took place. With the restoration of property rights and the introduction of free market rules, the construction of multi-family housing estates intensified, chaotically coinciding with the existing urban structure. In Cracow, the landscape of the historic city with an amazing development potential has begun to deteriorate due to the formation of architecturally inconsistent housing estates. In order to improve the quality of the space, the principles of sustainable development have been applied. However, theoretical assumptions were not always reflected in practice. The article raises the question whether housing estates created in the authoritarian system were more friendly to man and the environment, closer to the principles of sustainable development than multi-family housing units that are being created nowadays. The analysis of multi-family housing buildings created in two selected time intervals provides the opportunity to examine whether the "old" housing estates may have features worth imitating and whether new objects of this type should be further implemented in accordance with the developers' vision.

On the basis of the analyses, it can be stated that under the guise of shaping friendly spaces, we obtain objects that have been removed from the environment and isolate the inhabitants from the rest of the society. The article aims to compare two ways of creating architecture: before and after the period of political transformation in Poland, in order to determine patterns of building multi-family housing estates in accordance with the principles of sustainable development, which will be useful in the future.

Keywords: *sustainable development, sustainable housing estates, sustainable urban planning, political transformation, urban fabric degradation*

1. INTRODUCTION

In 1989, Poland underwent a political transformation, together with great social, and economic changes that also had a significant impact on the perception of urban space and the shape of architecture. The restoration of the free market rules (property rights, free trade in real estate, mortgage lending, change in the investment system - developer, etc.) intensified the construction of multi-family housing estates often chaotically inscribed in the existing urban fabric. Unfortunately, it frequently led to the degradation of urban space. People wanted to escape the architectural form shaped in the 60's and 70's, created according to political decisions, and ideologically formed the principle of industrialization of the design and implementation of the multifamily residential buildings (so-called „buildings production „) based on arbitrary planning and aesthetic decisions (home factories). Therefore the residents began to look for their own aesthetic solutions, expressing their needs and tastes, not necessarily resulting from previously received architectural or urban education.

Cracow is a very good example of a city that has suffered from the chaotic implementation of new multi-family housing estates. Its historic landscape, with an amazing development potential, has begun to lose its identity due to the formation of architecturally and urbanistically inconsistent housing estates. In order to improve the quality of space, the principles of sustainable development have been applied, focusing on ecological and economic design, developing social bonds, and above all, with a view to future generations. However, the design theory, which may have perfect effects in the future, both for the functioning of the city space and for the human being, is not fully reflected in reality. Under the pretext of creating spaces friendly to the inhabitants and the environment, developers create objects that do not meet the conditions of local development plans and destroy the surrounding urban fabric. While subsequent plots are reserved for residential purposes, the already existing settlements – most often created before 1989 are experiencing their renaissance. Implemented in the authoritarian system, when sustainable development was not clearly defined but manifested in the ideas of architects, and after a period of social depreciation, they begin to be perceived as attractive due to large amounts of green, recreational and people friendly areas. The contemporary architecture of housing estates in Poland draws a lot from the patterns created before 1989. The article aims to analyze multi-family housing buildings created in two-time intervals selected by the author in order to determine whether "old" housing estates may have features worth imitating, or the design methods used in their area, close to the principles of sustainable development have proven to be effective. And moreover to answer the question whether modern facilities of this type should continue to be implemented in accordance with the developers' vision.

2. THE PRINCIPLES OF SUSTAINABLE DEVELOPMENT IN THE CONTEXT OF MULTI-FAMILY HOUSING CONSTRUCTION

The concept of sustainable development concerns space management, which is supposed to provide proper living conditions not only for the present but also for future generations. It is perceived as a balanced development of three main priorities: ecology, economics and society along with its culture. It seems particularly important to apply the principles of sustainable development in architecture – a discipline that creates the surrounding space of a permanent character – durable, trying to create places perfectly suited to human needs, constantly interfering with the natural environment. The basic document defining the first directions of sustainable development was adopted at the 2nd Conference called "Environment and Development" organized by the UN in Rio De Janeiro in 1992. It included the assumptions that allowed in 1999 to create a document referring directly to architecture and defining the final Agenda – "Agenda 21 on sustainable construction." The main indicators of sustainable development in architecture and urban planning include:

-architectural and spatial aspects

a) in the context of the city space – impact on the surroundings, making the urban space more attractive, revitalization of the degraded areas, renovation and improvement of the degraded and existing architecture, rational spatial planning – division of the city space into zones in accordance with residents' needs, attracting people to the city centers and preventing the so-called urban sprawl – migration of the residents to the suburbs. A special importance in this context can be attributed to the logistics of the investment process that include the forecasting market needs as well as satisfying customer requirements. In case of the residential architecture, such actions should be undertaken by the developer. Efficient, ecological logistics operations – understood as the so-called Green logistic, provide an opportunity of foreseeing the potential of the specific plot and using it in a proper manner – beneficial not only for the investor but also for the whole city and future users of the space (in reference to sustainable design). Therefore, such understanding of the Green logistic should also include planning of the construction process, the supply of the specific materials and management of the investment in a manner that is environmentally friendly. Application of the environmentally friendly solutions results in the possibility of obtaining certificates such as BREEM or LEED.

b) in the context of architecture – the creation of "flexible" buildings, susceptible to modifications resulting from changing technologies, designed with the reference to the context, which affects the aesthetic durability of a given object

- social – humanitarian design – for people and to meet their needs. It concerns, among others integration of the residents, social participation – participation of the people in the investment process and the ability to determine their needs while maintaining care for the desires of the neighbour

- ecological – the use of renewable energy sources, materials susceptible to recycling, modern technologies, care for the appropriate climate in the building – interior zoning, the location of the rooms in accordance with world directions, the design of zero-energy or passive buildings, proper thermal protection

- economical – as little land use as possible, care for low operating costs, cheap material acquisition, architectural durability – use of materials that will not be quickly destroyed, time efficiency – quick access to workplaces, stores or schools. The city-business cooperation is also important, due to which, investors give away a part of the plot to the city in order to create space that is compatible with social expectations.

In Poland, however, the situation is more complicated. The issue concerns not only creating a new architecture in accordance with the principles of sustainable development but above all to renovate already existing housing buildings, created before 1989, which constitute the context and, to a great extent, a large part of the housing architecture. Objects created before the transformation period did not adapt to the currently set construction standards, yet they still exist and occupy a significant part of the city. Based on the adopted main methods of work: collecting data through queries in city and state archives, analysis of archival design and photographic materials, conducting local visions and interviews with the residents, it was possible to analyze the estates created before and after 1989 in the context of sustainable development.

3. DESIGN AND CONSTRUCTION OF KRAKÓW HOUSING ESTATES BEFORE 1989 IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Housing construction in Poland implemented before 1989 may be divided into several key periods. The first includes the post-war years when it was necessary to rebuilt damaged cities and respond to problems related to housing deficits. The 1949-1955 period was associated mainly with prevailing socialism, which did not give too many opportunities to create unique objects. The state was focused on building as many settlements as possible with the lowest costs of their implementation. It was only in the 1970s when the approach to residential architecture changed. Some freedoms began to appear in the creative expression of the architects, yet insufficient to match the Western Europe construction of this period. It was still the state that was an investor and decided where and how to build new buildings. Widely prevailing modernism and the desire to build quickly at a lower cost meant that large-scale prefabrication methods began to be applied in construction. Residential buildings similar in aesthetics and quality began to emerge everywhere, regardless of the context of the place. Interestingly enough, only after some time – more than 40 years – that we are able to check whether the adopted architectural and urban planning assumptions have worked or not, and only now we are able to draw meaningful conclusions regarding this issue. As Douglas Farr wrote in his book "Urban Design with nature": "Time is of the essence in adopting the reforms of sustainable urbanism".

3.1 Architectural and urban aspect

Estates created in Krakow between 1945 and 1989 were usually created in previously unbuilt areas – they did not have to fit the context, but they created it. They were frequently built in an excellent location, nearby newly designed arterial roads, which greatly influenced their connection to the city centre, workplaces and schools. Nowa Grzegórzecka, an urban planning assumption created in 1958-69, and Dąbie completed between 1965-1972, are perfect examples of such planning. Both of these settlements were built at the then-realized Aleja Pokoju, which was and still is the main connection between the centre of Krakow and Nowa Huta. Undoubtedly, it can be considered an advantage in the context of sustainable development, according to which the city should be a well-functioning tissue that makes life easier for its residents, including quick travel from one place to another.

The design process focused significantly on the very shape of the urban plan, which was to be self-sufficient and multifunctional in its structure. Therefore facilities such as schools, kindergartens, libraries and clinics were built nearby the blocks, which greatly simplified the lives of the residents and saved them valuable time.

Nowadays, such design is undoubtedly related to the broadly understood sustainable development. Architects also noticed the need to preserve a large number of green, recreational areas such as playgrounds, and to ensure the adequate distance between the buildings, allowing their proper insolation (Figure 1). In terms of urban planning, designed units were ideal and contained the elements characteristic for the garden cities (among others, composed greenery). The realities, however, were far from ideal. Due to the prevailing political system, the shops did not actually fulfil their role given the huge commodity deficit. Moreover, the large scale of urban planning was overwhelming. Today, in the changed political system, we are able to fully appreciate the urbanism of these settlements and use their potential, although it is often necessary to carry out some kind of modernization of previously planned urban layouts, as well as the buildings themselves. But because of their simple form that is susceptible to changes and adaptation to new technologies, which can be a model for architectural assumptions designed today. At the same time, it is a kind of a paradox that the totalitarian system created better urban planning than the one that should be more humane in its idea (the effect of the superiority of planning – the nationalization of space characteristic for authoritarian regimes). As far as the logistic of urban planning is concerned, we may state that the estates mentioned above constitute perfectly designed units not only in the context of the city but the whole country. Connected with a network of roads, they became a self-sufficient urban area.

The architecture of the discussed period is characterized by high uniformity of the buildings, but also of the construction methods. Since it was desired to build quickly, housing estates were created in a prefabrication technology. The assumption usually consisted of 3 – 4-storey buildings and several higher eleven-storey pointers. It is visible both in the area of Nowa Grzegórzecka and Dąbie, as well as Krowodrza Górka or Azory. According to the principles of sustainable development, the pure modernist shape of the buildings has its advantages, as it gives the possibility of manipulating the or adapting it to modern methods of construction. On the other hand, aesthetically uniform buildings increase landscape monotony, and the inability of the residents to express their individuality.

Figure 1 – Dąbie, a large amount of the green spaces, sufficient distance between the buildings

3.2 The social aspect

The new housing estates created in Poland in 1945-1989 were initially the answer to the problem of deficit sufficient quantity of available flats. On the other hand, their formation was related to the desire to bring cheap labour force from villages and smaller towns. The design process did not take into account the needs of the residents, but the needs of the state, which was focused on an intensive production process, requiring an appropriate number of employees. The apartments were imposed on the tenants from the allocation, not according to their requirements. These people were often not used to living in an urban environment. Arriving from the village for the first time, they could encounter modern technologies and frequently unfriendly urban environment. Then again, moving to a large metropolis signified an increase of the social and economic status. In the context of sustainable development, such design procedures, without taking into account the needs of the residents, are definitely not accepted.

3.3 The ecological aspect

As far as the ecology is concerned, the estates created before 1989 diverge from many standards. The main problem relates to the harmful materials, such as asbestos, used in the prefabrication process. Poor quality raw materials have led to a significant number of shortcomings of the construction, resulting in cracks on the facade, efflorescence or reduced insulation of the walls. Fortunately, due to the progress of technology, it is possible today to modernize existing blocks, which improves the quality of life but is not without further damage to the environment (subsequent construction works).

3.4 The economic aspect

It is impossible to hide the fact that the estates were created by the state and for the state. They were to be created quickly and cheaply, and consequently not necessarily in accordance with the broadly understood principles of sustainable development, which is a general tendency of a shortage system with technological and material deficits. Accepted prefabrication technologies made it possible to build economically, but the maintenance cost of the flats, made of poor quality materials, proved to be expensive – especially due to energy efficiency issues. It's the effect of so-called cheap energy which was one of the ideologically motivated system's priorities – to meet the living needs of the society (low wages – cheap housing).

4. THE INFLUENCE OF THE TRANSITION ON THE DESIGN OF HOUSING ESTATES AFTER 1989 IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

In 1989, after the transformation of the political system, not only the lifestyle of Poles gradually changed, but also the way they perceived the space. The sense of freedom and the possibility of owning a flat has completely altered the approach to investing. More and more people began to move to cities, and thus increased the demand for the new housing. A developer responsible for building large housing estates has appeared on the housing market, along with new urban assumptions chaotically implemented into the existing urban fabric. In order to improve the quality of gradually degraded space and attract new residents to large investments, new housing estates have been advertised as environmentally friendly and unique. Is this, however, true and consistent with the principles of sustainable development?

4.1 Architectural and urban aspect

New housing estates are most frequently created in very attractive districts of cities, among already existing buildings, often of a modernist character. In order to be able to implement a modern housing estate in Kraków, the developers acquire areas with high potential, e.g. recreational (which has little in common with the so-called Green logistic understood in the context of urban planning). It is clearly visible in case of the district of Grzegórzki Wschód, which is situated in a highly attractive location – close to the Vistula river. However, instead of developing high-quality recreational areas, it was decided to issue further building permits – for Wiślane Tarasy, Grzegórzecka 77, or the Pianissimo building, practically entering with their structure into the boulevards of the Vistula. These settlements occupy the areas previously reserved for factories – such as the Zieleniewski factory, which is being demolished for new investments, contrary to the principle of revitalization. Moreover, the new development does not refer to the context of the existing space and does not use its potential. Instead, created spaces with the disrupted scale and aesthetics do not match the existing urban fabric. Similarly to the settlements of the communist period, current construction market is dominated by the desire to create as many apartments as possible at the lowest price.

However, nowadays the plots are smaller than they used to be, and thus the creation of new buildings often takes place at the expense of poor insulation of the houses or lack of greenery. The density of the buildings increases significantly, and the individual blocks are located in the minimum, accepted by the regulations, distances that do not provide a full comfort. This phenomenon is particularly visible in the number of recreational, green areas, most often located above underground car parks, which makes the actual growth of plants almost impossible. An additional problem is the insufficient number of parking spaces or the prices of the underground garages. Such policy of developers leads to littering of the street space with cars, blocking pedestrian crossings and bicycle paths, which is definitely not an advantage considering the principles of sustainable development (Figure 2).

The architecture of the new settlements does not fit into the context and is chaotic. Modern residential objects treated as individual units look attractive, whereas when compared with each other in the quarters of buildings, they create a cacophony of forms. High-quality materials influencing the prestige of a given investment are meant to compensate for the shortcomings.

Figure 2 – Grzegórzecka 77, Wanda tenements – fencing of the settlements,
lack of parking spaces urban chaos

4.2 The social aspect

One of the main ideas of sustainable development includes social participation. In Poland, however, it is rarely used in housing construction – social consultations are more often organized as part of urban-business co-operation or the city projects. During the construction of housing estates, this process is usually overlooked. The relationship between the developer and the client is practically nonexistent. On the other hand, developers, wanting to respond to the increasingly excessive needs of the potential clients, try to create objects with diverse functions, giving the opportunity to develop and integrate residents by providing meeting rooms or gyms. What is important, the facilities are adapted to the needs of disabled people, which were previously overlooked during the design process. The question is, whether the people living in a large cluster of blocks really want to integrate. The lifestyle has changed, and we tend to spend more time on work, rather than on socializing.

An additional problem includes the fencing of the housing settlements. Originally designed to increase the safety of the residents, it begins to defragment the urban fabric and create enclaves – closed estates. In terms of sustainable development, it is a negative element.

4.3 The ecological aspect

Most methods of contemporary design and construction of housing estates make use of planning solutions of an ecological nature, and a green logistic character – starting with the use of recyclable materials, the use of alternative energy sources, by conducting construction in an environmentally friendly manner. Such actions, consistent with the needs and capabilities of the natural environment provide an opportunity of receiving certificates such as BREEM or LEED, that would increase the prestige of the investment. The only element that doesn't correspond with the pro-ecological planning of the space management is a frequent location of the settlements in places with high recreational potential, which seems to be negative in the scale of the city. The lack of proper analysis of the needs and benefits that a given area can have for the city and its inhabitants is clearly visible.

4.4 The economic aspect

Recently, a profit-oriented developer who has also become the investor began to manipulate indicators necessary to obtain a building permit, including determining the biologically active area, sun exposure and obscuration, or the number of parking spaces. Such behaviour means that under the guise of shaping ideal people-friendly spaces, created objects are inconsistent with the existing norms, and cause the degradation of the urban fabric

5. CONCLUSIONS

Despite the lack of clearly defined principles of sustainable development, housing estates designed and implemented before 1989 contain some of its elements. It is especially visible in urban planning. The housing estates were designed to be fully self-sufficient – there were libraries, schools, shops and clinics in their area. The designs also included a large number of green areas. However, due to the prevailing system, it was not possible to create an environment that would be close to perfection. Use of poor quality materials and prefabrication methods, and the desire to build as many apartments as possible resulted in large losses related to the issues of ecology. The situation was expected to change after the political transformation. The liberalization of the construction law, the creation of proprietary design offices and the withdrawal of the state from the investment process allowed to change its organization, but also led to some degradation of the urban space. This process, visible after 1989, was also the result of the destruction of the urban planning system (lack of comprehensive trans-spatial studies, spatial development plans and the idea of the so-called good neighbourhood as a form of the shaping of the urban space). This concept has led to the creation of a "city of developers" characterized by the lack of social control over the investment process and the arbitrary formula of the shaping of the functional systems of residential units. The idea of the city as a total organism has been lost. The effects include decomposition of urban and architectural space. The newly created spaces have become a collection of buildings, not an element of a rationally shaped urban system. Even the concept of sustainable development, which is nowadays much talked about, does not improve the quality of the space, as it is practically not implemented, or used to an unsatisfactory degree.

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